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AUDITORY AND ACOUSTICAL EVALUATION OF SEVERAL SHOULDER-RIFLES

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HUMAN ENGINEERING LABORATORIES

ABERDEEN PROVING GROUND,
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ABSTRACT

The threshold of audibility of each ear of 178 soldiers was measured before and after firing various types of shoulder rifles at the rate of one trigger pull every five seconds. The acoustical impulses from each type of weapon were evaluated (peak pressure, time history, and spectrum). The peak pressures of the acoustic impulses from firing the weapons were highly correlat. vith threshold shifts caused by exposure to the gun noise. From these and related data, estimates are made of the expected permanent hearing level in the frequency region from 1000 cps to 6000 cps to be equalled or exceeded in 50, 25, and 10 percent of ears repeatedly exposed to gun noise at various peak sound-pressure levels.

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AUDITORY AND ACOUSTICAL EVALUATION

OF SEVERAL SHOULDER-RIFLES

INTRODUCTION

There is ample evidence that the noise from some U. S. Army weapons can cause various degrees of permanent hearing loss in some of the persons exposed to the noise. There are at least two harmful results:

a. Persons incurring permanent hearing loss suffer a handicap that can affect the performance of their work and social activities for the rest of their lives.

b. Either a permanent or temporary hearing loss can be a hazard to operational personnel in that it impairs their ability to communicate and perceive auditory signals -- a weak speech signal or the snap of a twig while on patrol, for example.

There is not much quantitative data available that will permit one to correlate the measured physical characteristics of gun noise with degrees of hearing loss in persons exposed to the noise. The problem is obviously complex -- hearing loss is some function not only of the sound-pressure level present, as the result of a gun being fired, but also the number of rounds fired, the interval between firings, different person's differences in susceptibility to auditory damage from gun noise, the hearing level of the person before exposure to the noise, etc.

The problem has been further confounded by the fact that the physical measurements of gun noises -- usually peak pressure level -- did not always appear to be appropriate or sufficient descriptions of the noises' damage risk to hearing, even though all other factors that could influence hearing loss were held constant. However, there have recently been improvements in techniques for measurement and description both of gun noise and of the auditory acuity of persons exposed to gun noise.

To meet the requirements of the small-arms evaluation program, it appeared necessary to undertake a series of tests to measure the physical characteristics of noise from small arms, and the effects such noise had on hearing acuity (threshold of audibility) of persons firing the weapons. In view of the improved methods of measurement available, it also seemed possible that such a test program could lead to conclusions about hearing damage risk that might help establish criteria for exposure to gun noise in general. It should be noted that these auditory exposures were to be made and monitored so that the effects of the noise on hearing would presumably be of only a temporary nature, and that in no event were men to be exposed to firing procedures that were not the same as those to be found in many training and operational exercises.

Establishing acceptable damage-risk criteria -- how much hearing loss in what percentage of people should be considered tolerable -- involves value judgments about operational effectiveness as well as practical, economic, and ethical considerations that fall outside the responsibility of this report. Nevertheless, a later section will discuss the implications of damage-risk criteria that have been established or proposed by civilian and government agencies for defining limits of acceptable noise.

PURPOSES

The following are the purposes of this report:

a. To present the results of the acoustical measurements and auditory tests made for the small arms program.

b. To analyze the auditory data in terms of damage risk to hearing from exposure to the various weapons.

c. To relate the acoustical measurements of weapon noise to the results of the auditory tests.

d. To discuss using earplugs or earmuffs to reduce hearing loss from gun-noise exposure, and to examine the auditory problems that persons with and without noise-induced hearing loss have when communicating while wearing ear-protective devices.

PROCEDURE - AUDITORY TESTS

Subjects (Ss) were obtained from the 197th Infantry Brigade, Ft. Benning, Ga. These 178 men took a series of four pure-tone audiograms on a Rudmose ARJ-4 automatic audiometer in March 1964. The audiograms administered taught the Ss how to take an audiogram and provided an accurate hearing-threshold measure for each S. The audiograms were administered at Ft. Benning in either laboratory or office rooms, usually after work hours when the ambient noise level was low.

All firings for the temporary-threshold-shift (TTS) experiments took place the week of 11 May 1964 on the Farnsworth Range at Ft. Benning. TTS is determined by comparing an S's auditory acuity threshold before exposure to a noise and immediately after exposure to the noise. The difference between the pre- and post-exposure audiograms at each test frequency is called the "temporary threshold shift" or TTS. The word "temporary" is used because the threshold shifts (if any) from brief exposures to even very intense sounds, normally disappear within a few hours; in cases of extreme shifts -- 50 dB or more -- full recovery may require several days.

Because the auditory threshold usually returns to pre-exposure levels so rapidly, the time when threshold shift is measured for a frequency must be noted carefully so the measured threshold can be corrected to some common time base. It is customary to use two minutes post-exposure (called TTS_2) as a common reference time -- in other words, we wish to estimate what the threshold shift at each frequency would have been two minutes post-exposure regardless of when the threshold was actually measured. Inasmuch as it is not possible to measure at each frequency exactly two minutes after exposure, the measured thresholds are "corrected" to TTS_2 as shown in Figure 1. The maximum time difference between a TTS measurement and two minutes post-exposure was four minutes for the tests reported here.

Five ARJ-4 audiometers with otocups (special sound-insulating cushions that cover the audiometer earphones) were used. Audiograms were administered with the S seated in a portable metal booth (a so-called "Conex container") approximately 30 feet from the firing line. No firings took place while audiograms were being given, and the otocups further ensured that the audiograms were given without any noise interference or masking. The ARJ-4 audiometers were located outside the five test booths. Table 1 shows the octave band sound-pressure levels inside the booths.

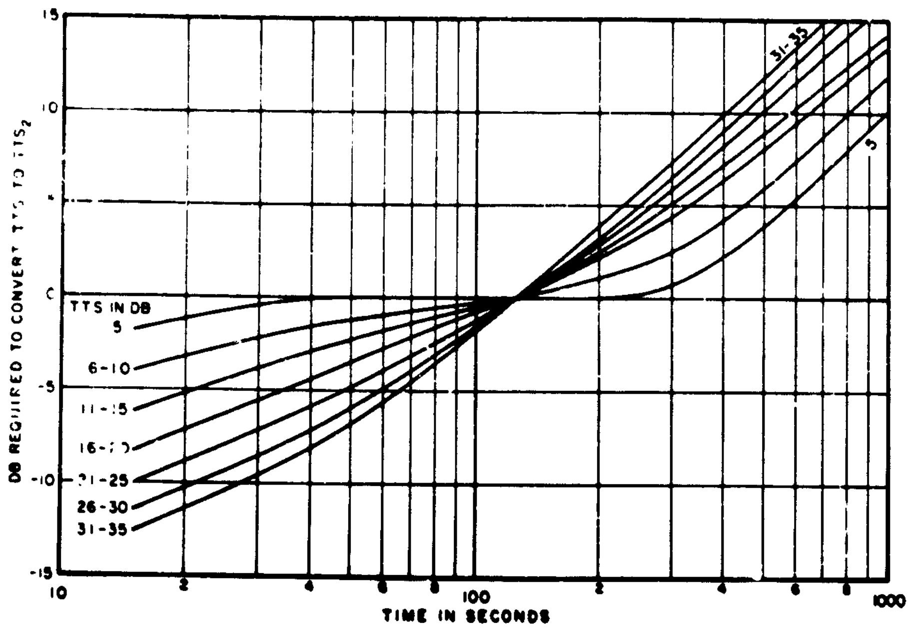


Fig. 1. GRAPH FOR CONVERTING TTS TO TTS_2, WITH TTS AS A PARAMETER

TABLE 1

Sound-Pressure Levels Inside Audiometric Test Booths

Octave-Band Center Frequency (cps)	Sound-Pressure Level (dB)	Maximum Allowable SPL ASA S3.1-1960
125	50	--
250	45	--
500	40	40
1000	36	40
2000	30	47
4000	25	52
8000	19	62

Immediately before a temporary-shift experiment, five Ss were given a pre-exposure hearing test. Then the Ss moved up to the firing line and assumed prone firing positions approximately 20 feet apart. The line officer signalled the time to start with a whistle. Every five seconds each man pulled the trigger of his weapon once. After a designated number of trigger pulls, the Ss immediately moved back to their respective audiometers. The hearing test began approximately 15 seconds after the last round was fired. All Ss were tested in the same manner. The firing schedule was as shown in Table 2.

TABLE 2

Firing Conditions[a]

	Number of trigger pulls/number of rounds per trigger pull									
Weapon	**15/1**	**30/1**	**60/1**	**100/1**	**50/2**	**85/2**	**100/2**	**10/3**	**20/3**	**30/3**
A	x	x	x	x				x	x	x
B	x	x	x	x	x	x	x			
C		x	x	x						
M-14				x						

[a]Because of some misfires on weapon A and weapon C, the actual number of rounds fired and the interval between some rounds differed somewhat from that planned.

AUDITORY TESTS: PART 1 -- PRE-EXPERIMENTAL AND PRE-EXPOSURE AUDIOGRAMS

The threshold of hearing for pure tones is usually measured in comparison to the threshold of normal young adult ears -- ears that have not been injured or damaged. The average threshold intensities for normal ears in the quiet are specified in American Standards Association (ASA) Standard Z24.5,* for various pure-tone frequencies. When an ear's hearing at a given frequency is that specified in ASA Z24.5, the ear is said to have a hearing level (HL) of 0 dB. If the tone must be 10 dB more intense than specified by ASA for a given frequency, the HL for that ear is said to be +10 dB; if an ear reaches threshold when the tone's intensity level is 10 dB less than the normal level specified, the HL for that ear is said to be -10 dB.

Pre-Experimental Hearing Levels

The average of the pre-experimental audiograms for the individual ears is given for each test frequency in Figures 2a-2e. Attention is invited to two features of these data. First, a large number of ears seem to have -10 dB HLs because standard audiometers do not measure HLs below -10 dB. Incidentally, the ASA specification for normal hearing appears to be in error by about 10 dB; that is, normal hearing is about 10 dB better, or more acute, than stated in the ASA specification. An International Standard on normal hearing aimed at correcting this deficiency has been adopted by the American Medical Association.

Second, and more important, Figure 2 shows that a large percentage of the soldiers used in this study -- probably a fairly typical sample of infantry soldiers -- have considerably less sensitive hearing than ASA "normal." Present VA standards are such that a man first becomes eligible for hearing-loss compensation when his average hearing level at 500, 1000, and 2000 cps in both ears is greater than 15 dB. By this criterion over ten percent of this group would appear to be eligible for some compensation if they were discharged from the military services at this stage of their careers. This finding is in agreement with previous hearing tests of Army personnel (4)

* American Standard Specification for Audiometers for General Diagnostic Purposes, Z24.5 (1951), American Standards Association, Inc., 10 E. 40th St., N.Y. 16, N.Y.

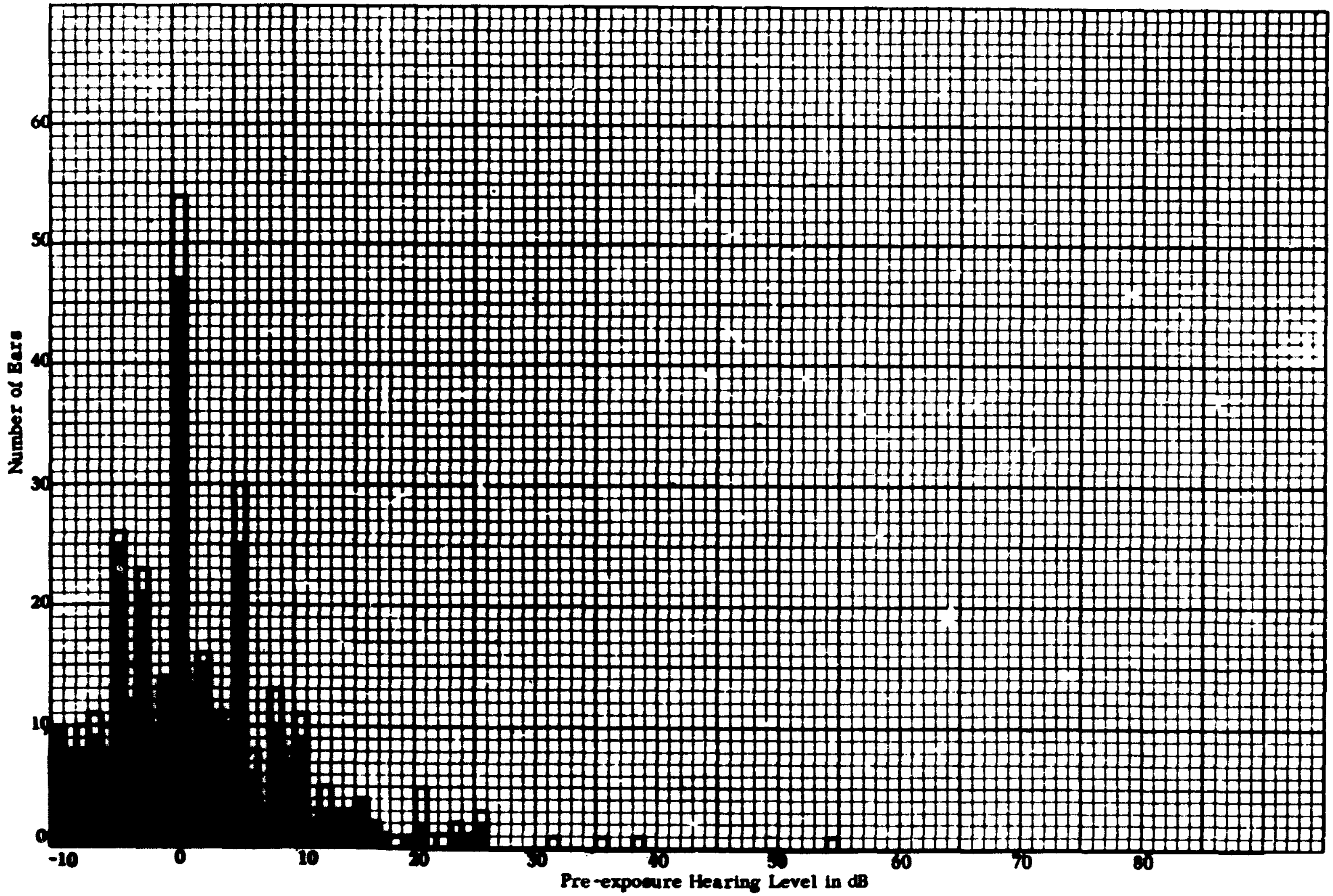


Fig. 2a. PRE-EXPOSURE HEARING LEVEL AT 1000 cps OF ALL EARS TESTED
(Unshaded portion represents ears eliminated from the study.)

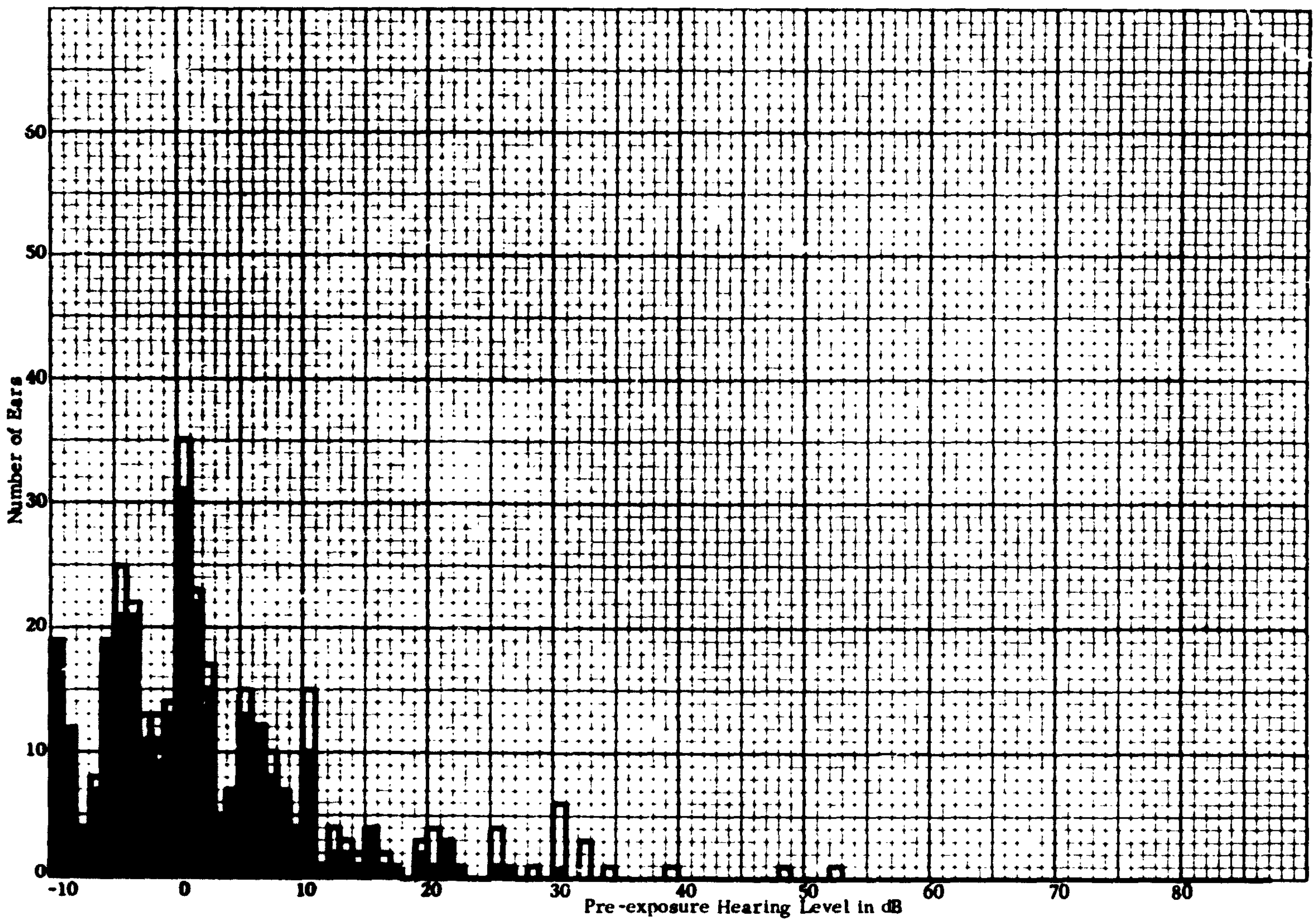


Fig. 2b. PRE-EXPOSURE HEARING LEVEL AT 2000 cps OF ALL EARS TESTED
(Unshaded portion represents ears eliminated from the study.)

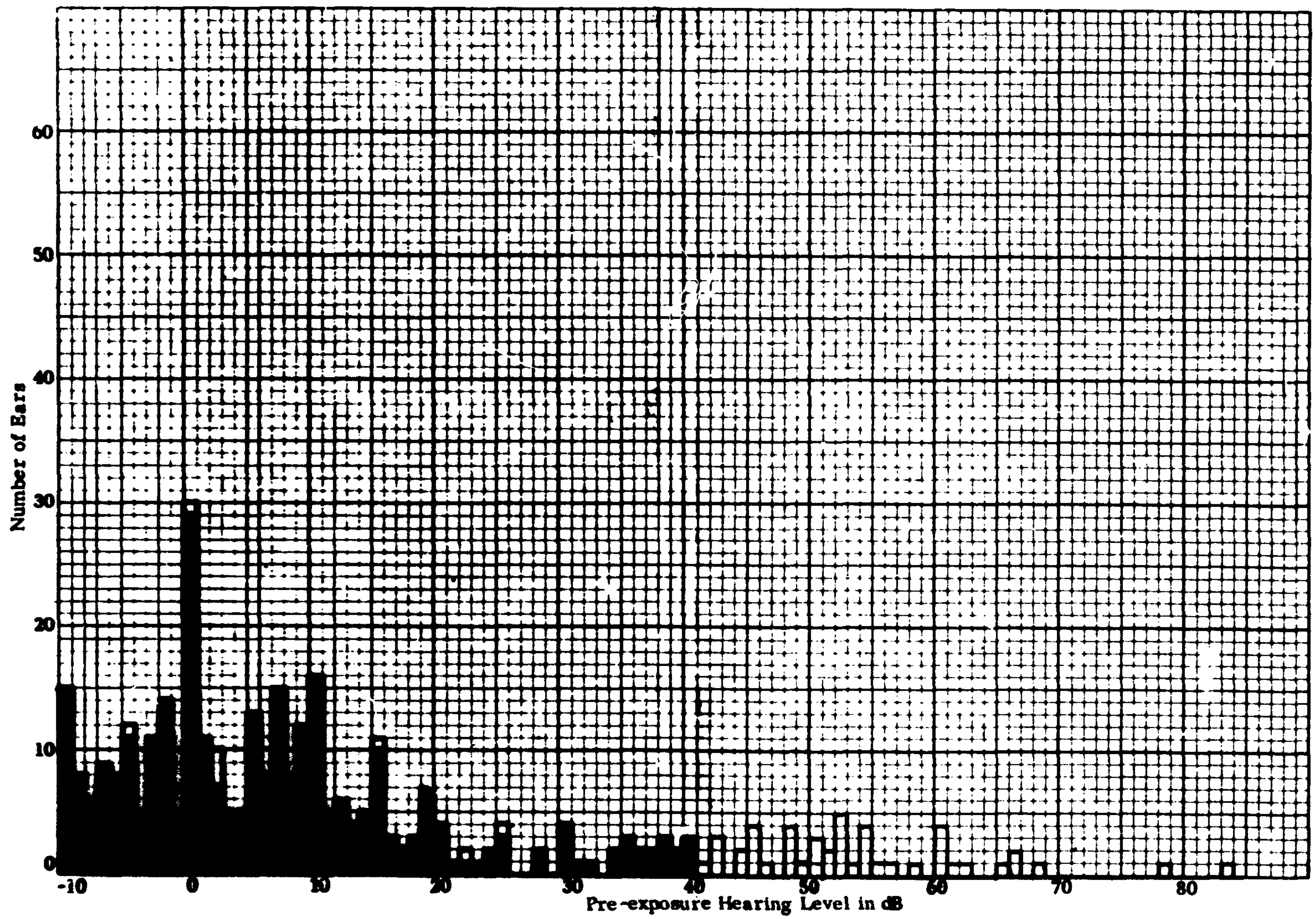
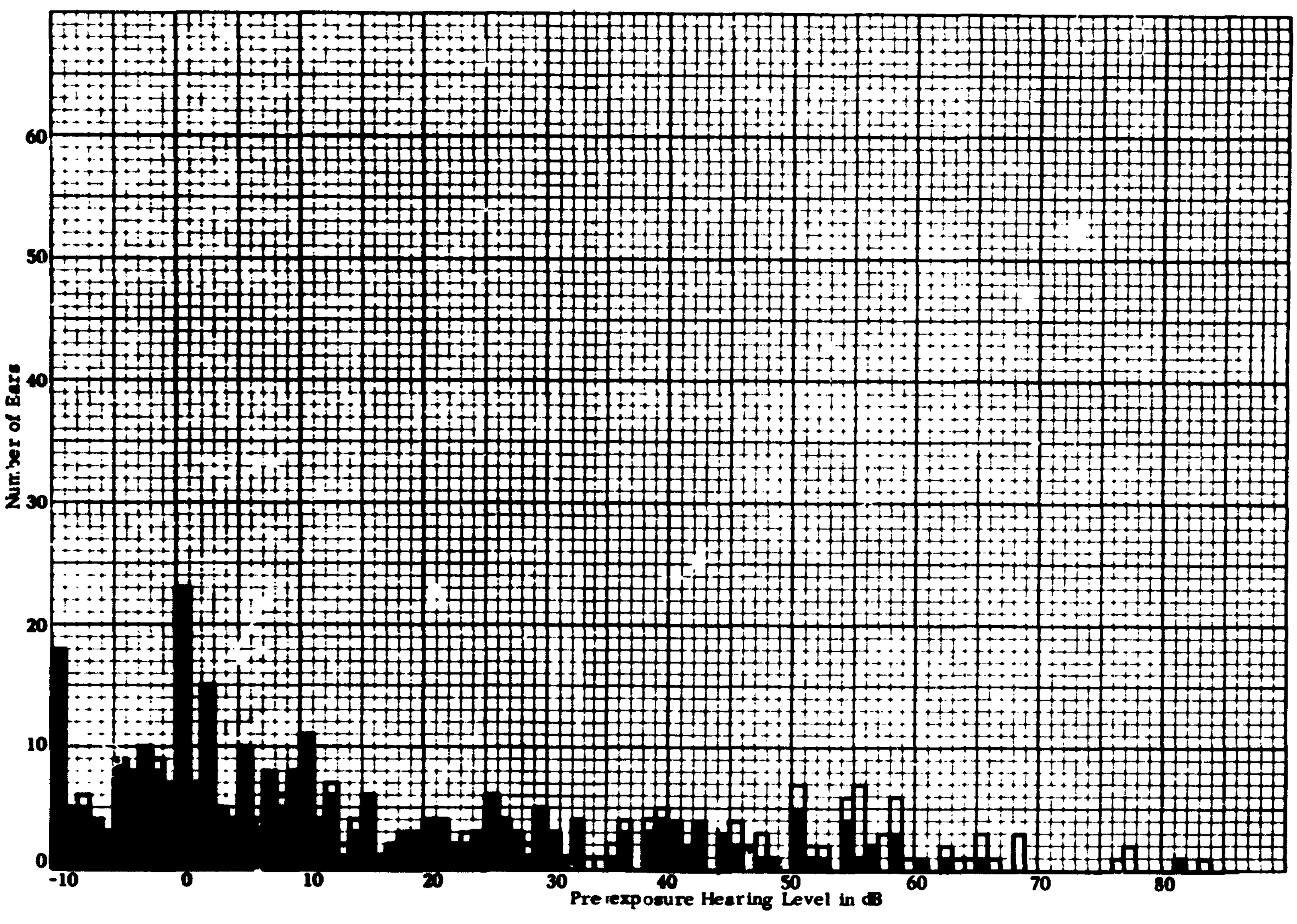


Fig. 2c. PRE-EXPOSURE HEARING LEVEL AT 3000 cps OF ALL EARS TESTED
(Unshaded portion represents ears eliminated from the study.)


Number of Ears
0
10
20
30
40
50
60
-10
0
10
20
30
40
50
60
70
80
Preexposure Hearing Level in dB

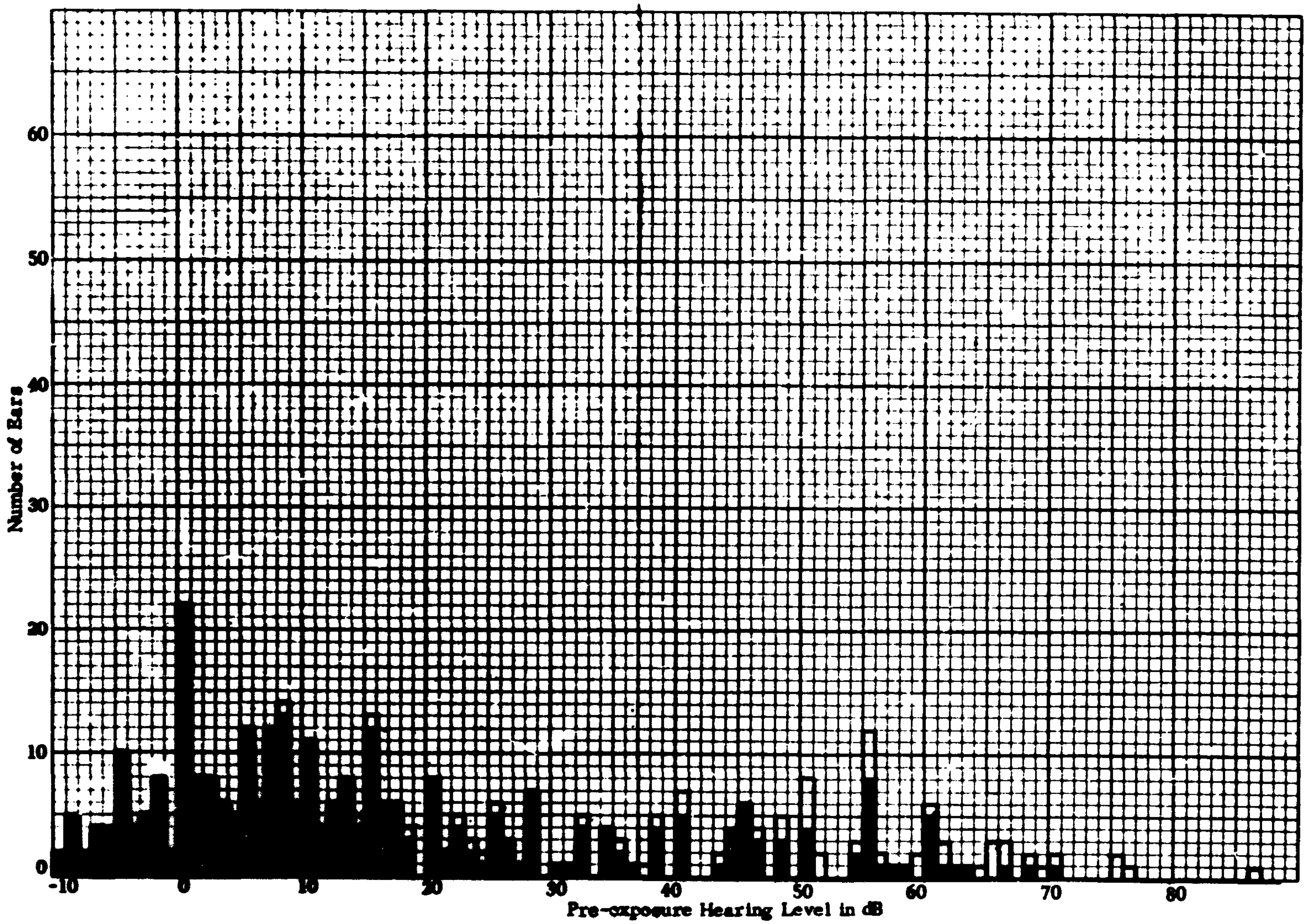


Fig. 2e. PRE-EXPOSURE HEARING LEVEL AT 6000 cps OF ALL EARS TESTED
(Unshaded portion represents ears eliminated from the study.)

Data Eliminated from Study

Although all the persons given pre-experimental audiograms participated in the firing, we later excluded data for some ears from our analysis of how firing affects hearing. The ears eliminated were those having pre-exposure HLs greater than 30 dB at 2000 cps or 40 dB at 3000 cps. Ears with this amount of pre-exposure hearing loss -- presumably permanent -- could hardly be expected to show any threshold shifts after the noise exposures planned for this experiment; it was planned to limit exposures to gunfire noise that would produce an average TTS of, hopefully, less than 30 dB at 2000 cps and 40 dB at 3000 cps. A total of 55 ears were eliminated from our test population of 356 ears.

Elimination of Audiometric Data for 500 cps

Although the hearing level at 500 cps was determined for each ear before and after each exposure to gun noise, we decided not to include these data in our evaluation of the effects of gun noise on hearing, for the following reasons:

a. Cursory examination of the results indicated that there were no consistent threshold shifts at 500 cps as the result of exposure to any of the firing conditions.

b. The 500-cps audiograms, which were always taken first in each audiometric test session, tended to be much more variable than those for the higher test frequencies. This variability is probably due, among other things, to the S's "warming up" and adjusting himself to the test procedures.

Near-Ear and Far-Ear Hearing Levels

It seems reasonable that the ear nearest the muzzle of a gun (the left ear when a person fires right handed, and vice versa) would accumulate a greater amount of hearing loss than the other or far ear, since acoustical measurements indicate that the sound-pressure level from a gun is usually about 1 dB greater at the near ear. Pre-exposure HLs and TTS_2 for the near ear and far ear are shown in Table 3 for the various sub-groups of Ss. The expected difference between near-ear and far-ear hearing does not appear consistently.

The near ear may indeed suffer more abuse from gun noise than the far ear, but these particular ears did not show this difference, possibly because past exposures to other noise sources had damaged their far ears. In any event, we considered each ear as a separate "subject," and in the remaining presentations of data the results obtained on each of an individual's ears are included as separate data points.

Pre-Exposure Hearing Levels

The average and median pre-exposure HLs were remarkably similar for the different groups of Ss used in the various firing conditions. That these groups were about equal on the average is clearly shown in Table 4, which gives the average of the average and median values at 1000, 2000, and 3000 cps. These frequencies were chosen for comparison because the auditory threshold at these three frequencies and at 500 cps is recognized as being much more important to normal, everyday hearing (particularly for speech) than is hearing at higher frequencies.

TABLE 3

Comparison of Near Ear and Far Ear for TTS_2 and Pre-exposure Hearing Level (Mean)

Wpn A, 32/1

	TTS_2 NE	TTS_2 FE	Pre-exposure HL NE	Pre-exposure HL FE
1000	4.6	4.0	2.7	3.7
2000	7.7	9.1	1.2	6.2
3000	8.9	19.5	8.6	13.8
4000	15.1	16.1	11.2	25.1
6000	7.9	19.0	20.6	23.6
Avg.	8.8	13.5	8.9	14.5

Wpn A, 13/3

	TTS_2 NE	TTS_2 FE	Pre-exposure HL NE	Pre-exposure HL FE
1000	1.5	-1	3.0	2.0
2000	12.0	2	4.0	-3.0
3000	17.5	-2	15.0	9.0
4000	0	-4	36.5	12.0
6000	35.5	23	-3.0	-2.0
Avg.	13.3	3.6	11.1	3.6

Wpn A, 74/1

	TTS_2 NE	TTS_2 FE	Pre-exposure HL NE	Pre-exposure HL FE
1000	10.0	7.5	5.3	2.0
2000	20.3	27.3	2.3	-4.3
3000	23.7	57.5	12.0	-1.5
4000	20.7	66.0	18.0	8.5
6000	40.0	51.3	14.7	-4.5
Avg.	23.0	42.0	10.5	0.4

Wpn A, 24/3

	TTS_2 NE	TTS_2 FE	Pre-exposure HL NE	Pre-exposure HL FE
1000	2.2	5.0	0.5	-2.2
2000	4.6	4.1	1.9	3.8
3000	7.3	5.4	1.8	6.4
4000	9.9	4.2	6.3	6.6
6000	8.8	1.1	12.3	14.8
Avg.	6.6	4.0	4.6	5.9

Wpn A, 102/1

	TTS_2 NE	TTS_2 FE	Pre-exposure HL NE	Pre-exposure HL FE
1000	11.3	15.8	1.7	-0.3
2000	28.7	33.5	-0.3	1.0
3000	36.7	32.4	-1.3	10.8
4000	47.3	33.4	1.0	21.8
6000	29.3	26.8	22.7	24.4
Avg.	30.6	28.4	4.8	11.5

Wpn A, 30/3

	TTS_2 NE	TTS_2 FE	Pre-exposure HL NE	Pre-exposure HL FE
1000	1.7	-1.3	-0.3	-3.0
2000	6.3	13.0	-1.3	2.0
3000	14.0	6.0	-2.0	11.5
4000	2.7	1.8	12.0	15.3
6000	20.0	3.3	10.3	18.0
Avg.	8.9	4.6	3.7	8.8

Table 3 - continued

Wpn B, 30/1	TTS_2 NE	TTS_2 FE	Pre-exposure HL NE	Pre-exposure HL FE
1000	-1	1	3	0
2000	3	2	4	0
3000	4	5	11	2
4000	3	6	16	10
6000	3	7	28	18
Avg.	2.4	4.2	12.4	6.0

Wpn B, 100/2	TTS_2 NE	TTS_2 FE	Pre-exposure HL NE	Pre-exposure HL FE
1000	1	5	-3	-3
2000	5	4	1	-4
3000	4	1	10	6
4000	5	2	14	14
6000	8	6	13	11
Avg.	4.6	3.6	7.0	4.8

Wpn B, 60/1	TTS_2 NE	TTS_2 FE	Pre-exposure HL NE	Pre-exposure HL FE
1000	2	2	1	1
2000	5	5	1	-2
3000	6	7	6	6
4000	6	5	8	11
6000	11	[illegible]	8	18
Avg.	6.0	4.4	4.8	6.8

Wpn B, 170/2	TTS_2 NE	TTS_2 FE	Pre-exposure HL NE	Pre-exposure HL FE
1000	0	1	-3	-6
2000	0	5	4	-5
3000	6	14	11	-6
4000	14	24	8	16
6000	19	5	10	19
Avg.	7.8	9.8	6.0	3.6

Wpn B, 100/1	TTS_2 NE	TTS_2 FE	Pre-exposure HL NE	Pre-exposure HL FE
1000	3	4	2	2
2000	5	13	2	-1
3000	19	15	8	5
4000	18	19	17	8
6000	28	16	17	19
Avg.	14.6	13.4	9.2	6.6

Wpn B, 200/2	TTS_2 NE	TTS_2 FE	Pre-exposure HL NE	Pre-exposure HL FE
1000	2	3	3	0
2000	8	7	2	-1
3000	13	12	5	6
4000	13	4	9	15
6000	10	3	15	16
Avg.	9.2	5.8	6.8	7.2

Table 3 - continued

Wpn C, 23/1	TTS$_2$		Pre-exposure HL	
	NE	FE	NE	FE
1000	-7	4	6	3
2000	2	9	1	4
3000	0	22	5	6
4000	2	34	-2	3
6000	10	41	4	12
Avg.	1.4	22.0	2.8	5.6

M14, 100/1	TTS$_2$		Pre-exposure HL	
	NE	FE	NE	FE
1000	2	2	0	-2
2000	4	6	-1	-4
3000	8	5	1	0
4000	5	10	8	14
6000	8	8	17	19
Avg.	5.4	6.2	5.0	5.4

Wpn C, 63/1	TTS$_2$		Pre-exposure HL	
	NE	FE	NE	FE
1000	4	6	4	5
2000	4	2	2	0
3000	14	9	8	2
4000	18	5	9	2
6000	23	5	12	19
Avg.	12.6	5.4	7.0	5.6

Wpn C, 97/1	TTS$_2$		Pre-exposure HL	
	NE	FE	NE	FE
1000	6	-1	0	2
2000	10	3	-1	3
3000	10	2	7	6
4000	12	5	11	7
6000	15	6	16	13
Avg.	10.6	3.0	6.6	6.2

TABLE 4

Average and Median Pre-exposure Hearing Levels
for 1000, 2000, and 3000 cps

Weapon	Exposure[a]	Average	Median
A	17/1	0.7	1.3
	32/1	6.0	5.0
	74/1	3.2	1.0
	102/1	2.4	4.0
	6/3	2.4	4.3
	13/3	5.8	5.0
	24/3	2.0	-0.7
	30/3	1.2	0.3
B	15/1	6.4	6.7
	30/1	3.6	2.0
	60/1	2.3	1.3
	100/1	2.7	2.0
	50/2	-0.9	-1.3
	85/2	0	-2.0
	100/2	2.5	1.7
C	23/1	4.1	3.7
	63/1	3.8	4.0
	97/1	2.9	3.3
M-14	100/1	-1.0	-1.3

[a] Number of trigger pulls/number of rounds per trigger pull

AUDITORY TESTS: PART 2 -- TTS_2 AND HL_2

Table 5 summarizes the statistical analyses of the audiometric data obtained from Ss before and after exposure to the various firing conditions. The average and the 25th (Q_1), 50th (median or Q_2), and 75th (Q_3) percentiles, as well as the number of ears, are given in Table 5 for most of the firing conditions, but Q_1, Q_2, and Q_3 values were not determined for some of the firing conditions that caused only small threshold shifts.

TTS_2 Results

It can be argued that either the average or the median best describes the central tendency of the data at hand. Since these data were in most cases skewed, the average seems the more logical choice if we wish to find the amount of hearing loss one can expect from exposure to a given firing condition; on the other hand, the median should tell us the level of hearing loss that would be exceeded by 50 percent of the exposed population.

We therefore examined both the average and median TTS_2 values for each of the various firing conditions and tried to relate them to the number of trigger pulls and audiometer test frequency. The averages seemed to give somewhat smoother results than the medians; mean TTS_2, for example, increased more regularly as a function of number of trigger pulls for a given weapon than did median TTS_2.

The irregularities and inconsistencies can reasonably be attributed to the relatively small number of Ss and differences among the ears used in some of the firing conditions, as well as some experimental errors always present in "field" experiments of this type.

HL_2 Results

Although the ears for each group had comparable pre-exposure average and median HLs (Table 4), there were still relatively large differences among the individual ears, as indicated by the size of Q_3 (Table 5). This may mean that some artifact arises from comparing TTS_2 values for the different firing conditions.

Conceivably, if not probably, individual ears' differences in pre-exposure HLs would influence the amount of TTS_2 measured; for example, an exposure condition capable of causing a 15 dB TTS_2 in an ear with a pre-exposure HL of 0 dB might cause a much smaller TTS_2, if any, in an ear with a pre-exposure HL of, say, 15 dB. We have attempted to account for these individual differences in pre-exposure HLs, at least to some extent, by adding together TTS_2 and pre-exposure HL to achieve "HL_2," or the actual hearing level for an ear measured two minutes after exposure to a given noise condition.

TABLE 5

Summary of Data for Pre-Exposure Hearing Level, TTS_2 and HL_2

	Pre-Exposure Hearing Level					TTS_2 (Test Frequencies in KC)					HL_2				
	1	2	3	4	6	1	2	3	4	6	1	2	3	4	6
Wpn A -- No. of trigger pulls - 17/1															
No. of ears = 9															
Average	-4.4	-0.5	4.0	2.9	6.8	5.6	7.4	12.1	24.9	23.8	3.6	7.0	16.1	24.6	30.5
Q_1	-6	-6	-5	-3	-2	-5	1	2	0	0	1	0	8	10	6
Median(Q_2)	-2	0	6	5	11	2	4	1	27	16	5	4	11	18	24
Q_3	2	7	13	10	15	8	16	32	48	47	8	10	27	41	57
Wpn A -- No. of trigger pulls - 32/1															
No. of ears = 18															
Average	3.2	3.7	11.2	18.2	22.0	4.3	8.4	13.9	15.6	13.1	7.5	12.1	25.1	33.8	35.1
Q_1	-8	-4	4	2	9	0	2	-2	2	0	2	5	5	11	12
Median(Q_2)	1	1	13	21	21	5	5	5	6	7	5	6	20	27	20
Q_3	10	15	18	31	38	6	12	24	25	20	10	16	27	60	57
Wpn A -- No. of trigger pulls - 74/1															
No. of ears = 6															
Average	4.0	-1.0	6.6	14.2	4.3	9.0	23.9	37.2	38.8	45.7	13.0	22.9	43.8	53.0	50.0
Q_1	-5	-6	-9	-6	-9	-4	4	5	2	0	-2	-3	9	14	-8
Median(Q_2)	0	-3	6	8	-4	12	30	16	42	47	12	25	44	71	72
Q_3	15	7	23	20	17	19	62	50	69	71	22	50	5	85	86
Wpn A -- No. of trigger pulls - 102/1															
No. of ears = 6															
Average	0.6	0.4	6.3	14.0	23.8	13.9	31.4	34.0	38.7	27.8	14.5	31.8	40.3	52.7	51.6
Q_1	-2	-8	-7	-3	0	3	2	3	19	4	0	7	6	14	5
Median(Q_2)	0	2	10	12	7	13	15	6	31	6	16	17	50	49	66
Q_3	3	9	15	28	52	23	54	56	55	18	26	56	84	84	91
Wpn A -- No. of trigger pulls - 6/3															
No. of ears = 6															
Average	3.0	-0.3	4.4	11.2	7.0	2.8	3.8	8.8	7.3	4.8	5.8	3.5	13.2	18.5	11.8

Table 5 - continued

	Pre-Exposure Hearing Level					TTS_2					HL_2				
	Test Frequencies in KC														
	1	2	3	4	6	1	2	3	4	6	1	2	3	4	6
Wpn A - No. of trigger pulls - 13/3															
No. of ears = 3															
Average	2.7	1.7	13.0	28.3	-2.7	0.7	8.7	11.0	-1.3	31.3	3.4	10.4	24.0	27.0	28.6
Wpn A - No. of trigger pulls - 24/3															
No. of ears = 19															
Average	-0.9	2.8	4.1	6.4	13.5	3.6	4.4	6.4	6.7	4.6	2.7	7.2	10.5	13.1	18.2
Wpn A - No. of trigger pulls - 30/3															
No. of ears = 7															
Average	-1.9	0.3	5.1	13.9	14.7	0	9.7	9.4	2.1	10.4	-1.9	10.0	14.5	16.0	25.1
Wpn B - No. of trigger pulls - 15/1															
No. of ears = 16															
Average	3.2	-0.4	16.1	27.1	23.3	2.2	3.8	4.6	-0.5	1.8	5.4	3.4	20.7	26.6	25.1
Wpn B - No. of trigger pulls - 30/1															
No. of ears = 21															
Average	1.7	2.3	6.7	13.1	23.4	-0.2	2.3	4.5	4.6	4.5	1.5	4.6	11.2	17.7	27.9
Q_1	-1	-3	-1	0	7	-3	-1	1	-4	-2	-2	-1	1	4	6
Median(Q_2)	0	1	5	9	19	1	1	4	3	3	1	4	6	10	21
Q_3	5	8	17	21	40	3	4	8	12	10	6	9	24	24	55
Wpn B - No of trigger pulls - 60/1															
No. of ears = 35															
Average	1.1	-0.5	6.2	9.4	13.3	2.1	5.1	6.2	5.4	6.6	3.2	4.6	12.4	14.8	19.9
Q_1	-4	-6	-3	0	5	-1	0	0	-1	-1	-2	-2	0	-1	5
Median(Q_2)	0	1	5	5	10	1	2	3	1	1	1	2	8	9	15
Q_3	5	2	11	18	28	4	10	10	9	16	8	10	22	25	29

Table 5 - continued

	Pre-Exposure Hearing Level					TTS_2					HL_2				
	Test Frequencies in KC														
	1	2	3	4	6	1	2	3	4	6	1	2	3	4	6
Wpn B - No. of trigger pulls - 100/1															
No. of ears = 36															
Average	2.0	0.4	6.5	12.2	18.1	3.7	8.6	17.1	18.2	22.2	5.7	9.0	22.6	30.4	40.3
Q_1	-3	-4	-2	-1	-1	1	1	3	3	4	5	5	3	5	13
Median(Q_2)	2	1	3	3	14	3	4	8	12	17	-1	0	12	18	44
Q_3	6	5	9	20	27	5	13	25	30	40	10	12	43	52	57
Wpn B - No. of trigger pulls - 50/2															
No. of ears = 17															
Average	3.1	-1.4	7.2	13.9	12.1	2.8	4.8	2.4	3.7	6.7	-0.3	3.4	9.6	17.6	18.8
Wpn B - No. of trigger pulls - 85/2															
No. of ears = 11															
Average	-4.5	0.4	4.1	11.0	14.4	0.5	2.4	9.8	17.7	12.7	-4.0	2.8	13.9	28.7	27.1
Wpn B - No. of trigger pulls - 100/2															
No. of ears = 23															
Average	1.4	0.6	5.6	12.2	15.6	2.2	7.5	12.2	8.4	6.5	3.5	8.1	17.8	20.6	22.1
Wpn C - No. of trigger pulls - 23/1															
No. of ears = 5															
Average	4.0	2.6	5.6	1.2	9.0	-0.2	6.0	13.0	21.4	28.2	3.8	8.6	18.6	22.6	37.2
Q_1	2	0	0	-3	0	-8	-1	3	2	8	-3	0	9	0	16
Median (Q_2)	4	0	7	0	4	-3	1	11	4	13	3	2	19	40	59
Q3	7	7	11	7	21	0	3	11	50	56	12	18	51	65	73

Table 5 - continued

	Pre-Exposure Hearing Level					TTS_2					HL_2				
	Test Frequencies in KC														
	1	2	3	4	6	1	2	3	4	6	1	2	3	4	6
Wpn C - No. of trigger pulls - 63/1															
No. of ears = 12															
Average	2.9	1.6	6.9	13.4	13.1	4.8	3.3	11.7	13.0	15.4	7.7	4.9	18.6	26.4	28.5
Q_1	-1	-5	0	0	-3	0	-1	-2	1	1	5	0	5	4	6
Median (Q_2)	2	3	7	9	9	3	5	4	11	8	7	5	10	32	19
Q_3	8	6	11	29	15	9	8	16	36	35	11	12	38	55	56
Wpn C - No. of trigger pulls - 97/1															
No. of ears = 27															
Average	1.4	0.7	6.5	9.1	14.7	2.4	6.2	6.2	8.7	10.3	3.8	6.9	12.7	17.8	25.0
Q_1	-5	-5	0	-3	4	-2	2	-1	-2	-2	-3	-2	-2	-1	7
Median (Q_2)	1	5	4	6	12	1	4	2	7	4	-2	1	8	4	2
Q_3	5	13	13	14	26	9	9	11	20	22	7	10	12	14	27
M-14 - No. of trigger pulls - 100/1															
No. of ears = 30															
Average	-0.9	-2.5	0.3	10.7	18.2	2.0	5.0	6.1	7.3	8.3	1.1	2.5	6.3	18.0	26.5
Q_1	-5	-7	-6	-4	0	-2	1	0	0	0	-4	-4	-4	2	4
Median (Q_2)	-1	-3	0	7	15	3	3	2	6	3	0	1	4	8	26
Q_3	3	1	7	25	40	5	8	13	12	10	7	8	14	33	45

This procedure is supported to some extent by experimental evidence (2) that the amount of TTS_2 after exposure to continuous steady-state noise is inversely proportional to pre-exposure hearing level; that is, a noise exposure that causes a TTS_2 of 30 dB in persons with a pre-exposure HL of 0 will cause a TTS_2 of approximately 15 dB in persons with a pre-exposure HL of 15 dB.

Examining the data on TTS_2 after exposure to gunfire suggested a similar phenomenon -- the sum of pre-exposure HL and TTS_2 for a given exposure condition was, on the average, a constant, provided that pre-exposure HL did not greatly exceed the average amount of TTS_2 suffered by persons with pre-exposure HLs of 0 dB. This "rule" was violated by a sizeable number of subjects who seemed to have extra "tough" ears; these ears not only had normal or better than normal hearing, they also showed little or no TTS_2 as a result of exposure to the gun noise.

This proposed additivity rule (TTS_2 + pre-exposure HL = a constant) is, particularly for exposure to impulse noise, based on an unproved assumption. However, this procedure gives values, HL_2, which seem to estimate the ultimate criterion more closely than TTS_2 does: HL_2 is believable as the amount of threshold shift one would expect from exposing carefully matched groups of ears (the ideal but unachieved arrangement for our experiments) to the various firing conditions.

Figures 3a through 3e present average HL_2 as a function of the number of trigger pulls; Figures 4a through 4d present average HL_2 as a function of the audiometric test frequencies. We see in these figures that the type of weapon and number of trigger pulls influence the HL_2 values for the different audiometric test frequencies. The pre-exposure hearing level is also included in these figures to show, on the average, the amount of TTS_2 produced by the various weapons. Later in the report, we will attempt to relate some of these data to the physical characteristics of the noises and to the damage risk to hearing.

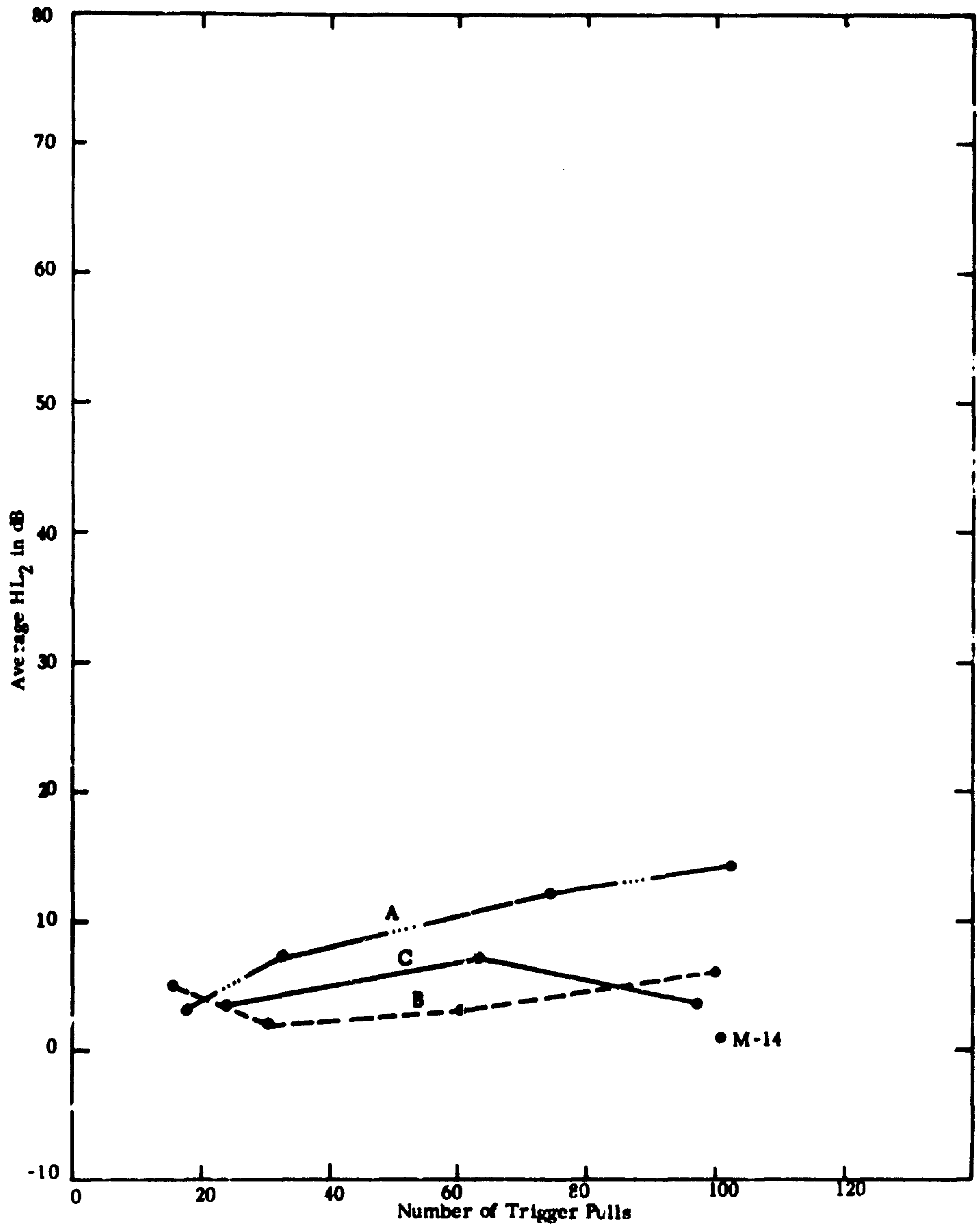


Fig. 3a. AVERAGE HL_2 AS A FUNCTION OF THE NUMBER OF TRIGGER PULLS OF THE TESTED WEAPONS FOR THE 1000-cps AUDIOMETRIC TEST FREQUENCY

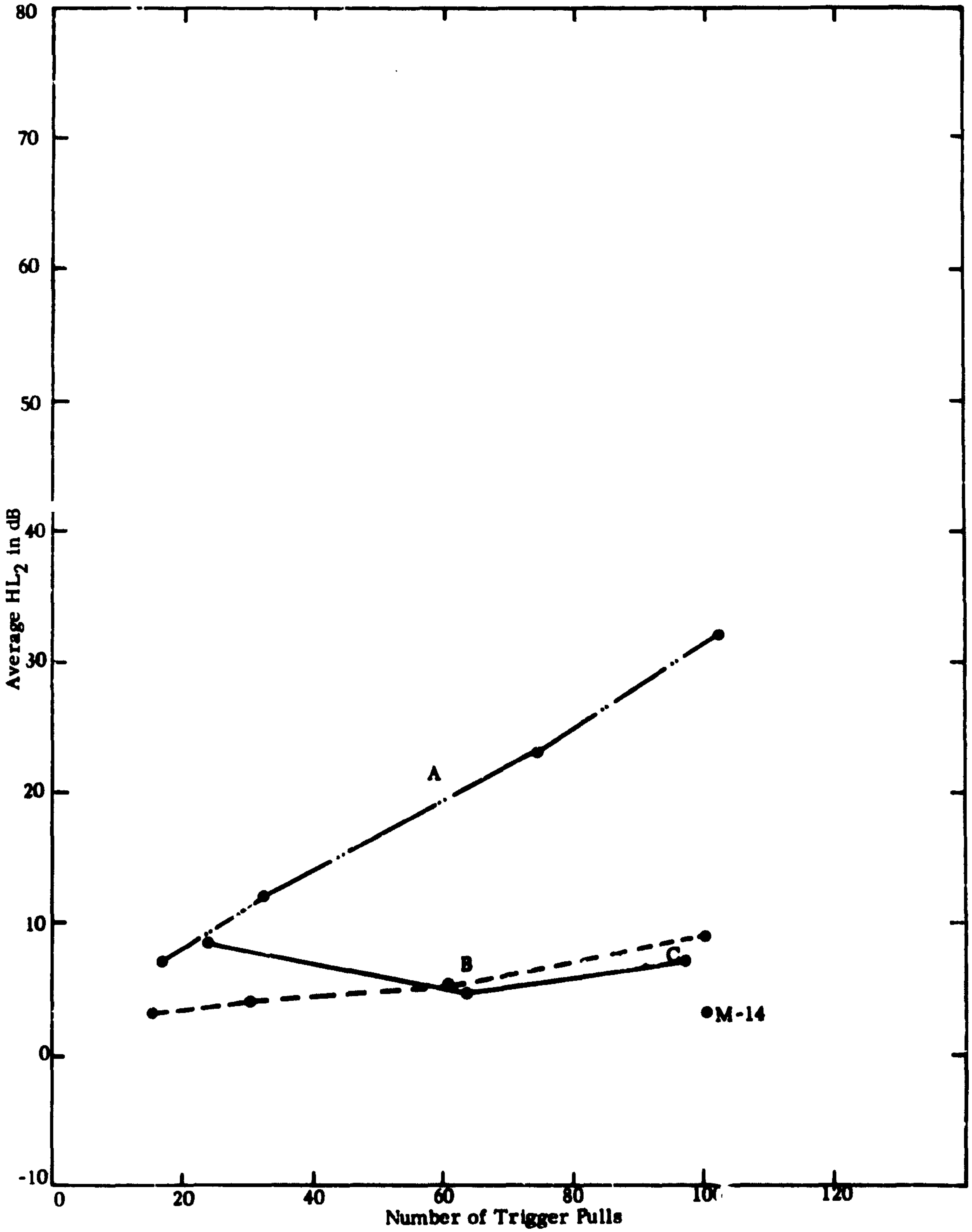


Fig. 3b. AVERAGE HL_2 AS A FUNCTION OF THE NUMBER OF TRIGGER PULLS OF THE TESTED WEAPONS FOR THE 2000-cps AUDIOMETRIC TEST FREQUENCY

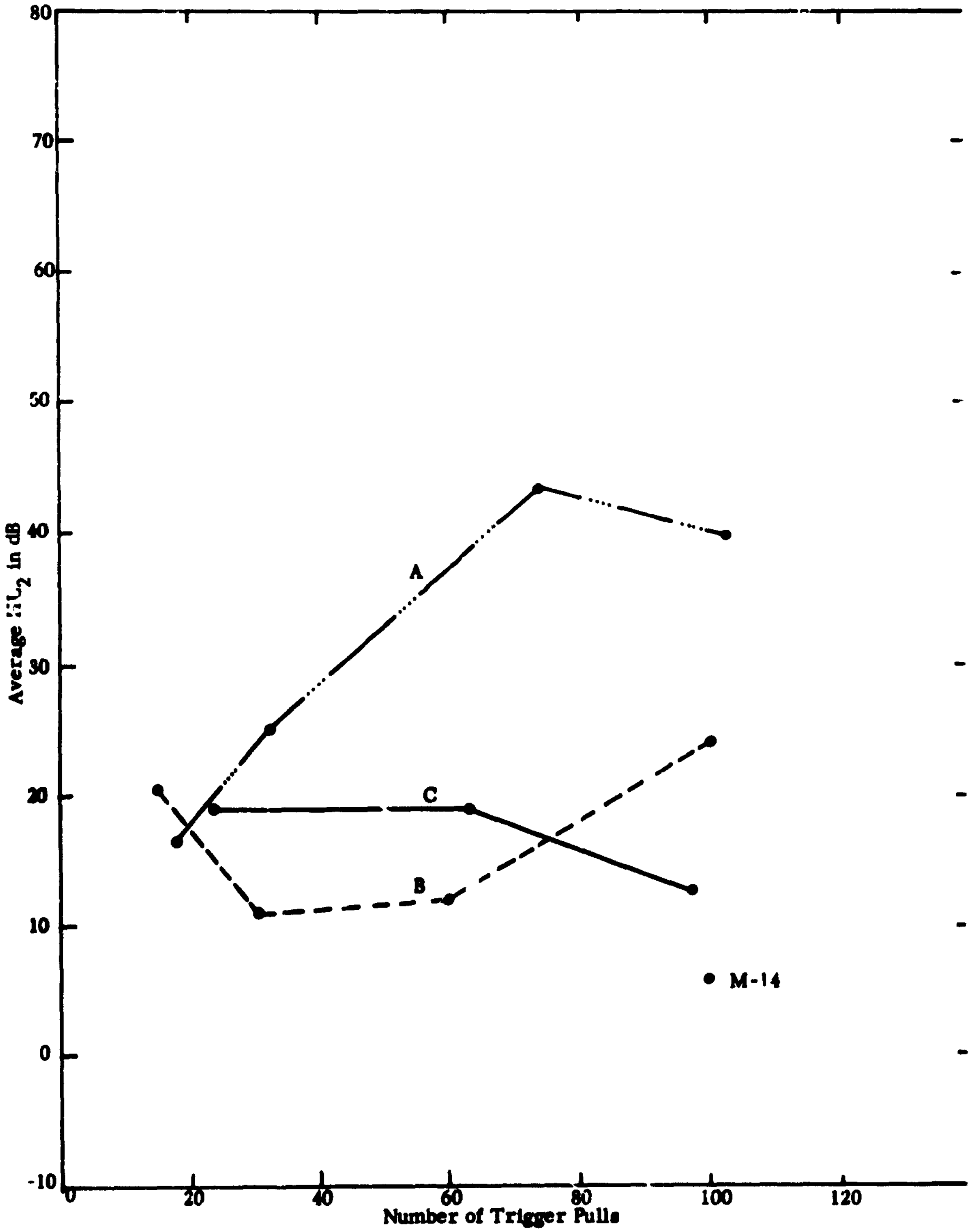


Fig. 3c. AVERAGE HL_2 AS A FUNCTION OF THE NUMBER OF TRIGGER PULLS OF THE TES D WEAPONS FOR THE 3000-cps AUDIOMETRIC TEST FREQUENCY

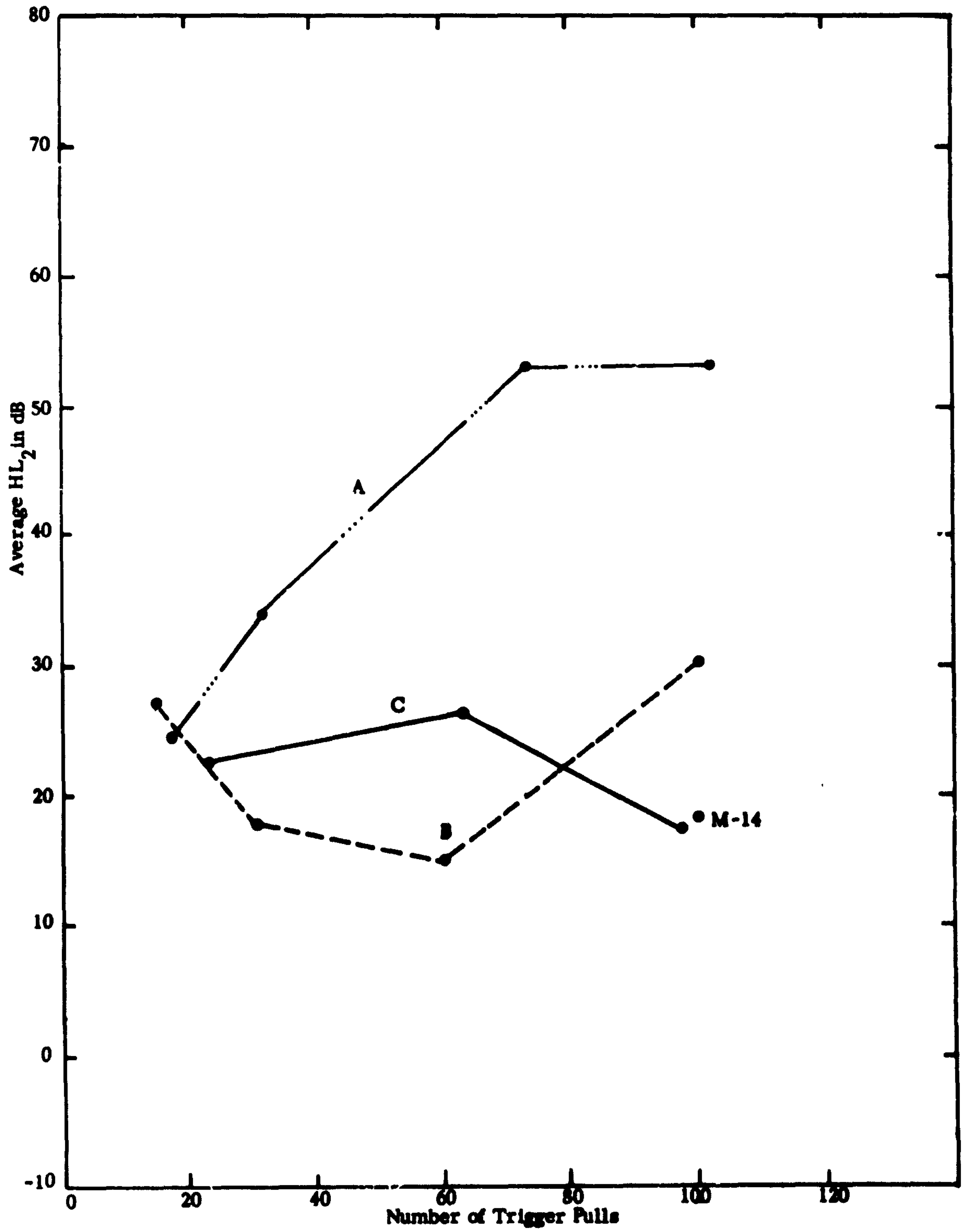


Fig. 3d. AVERAGE HL_2 AS A FUNCTION OF THE NUMBER OF TRIGGER PULLS OF THE TESTED WEAPONS FOR THE 4000-cps AUDIOMETRIC TEST FREQUENCY

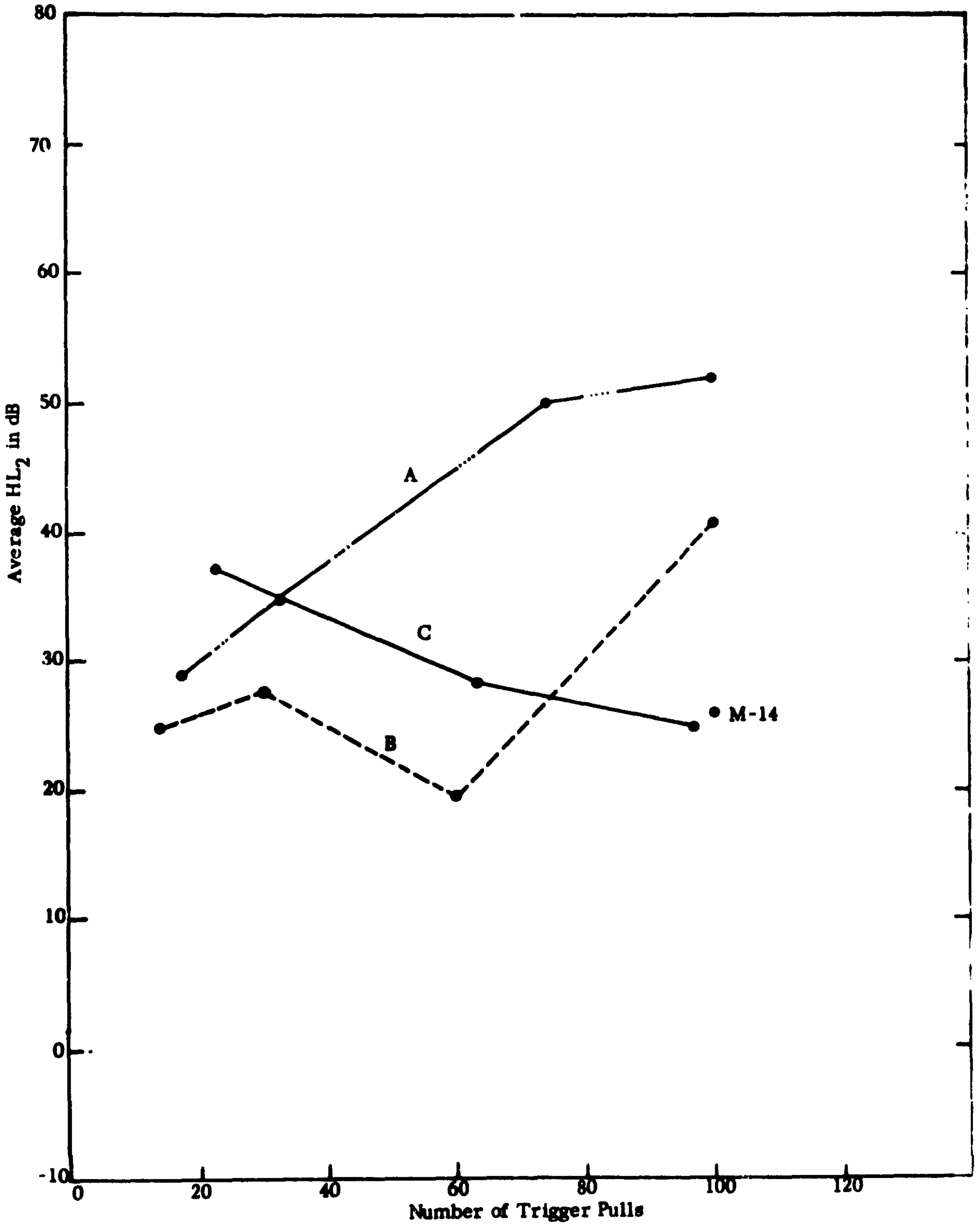


Fig. 3e. AVERAGE HL_2 AS A FUNCTION OF THE NUMBER OF TRIGGER PULLS OF THE TESTED WEAPONS FOR THE 6000-cps AUDIOMETRIC TEST FREQUENCY

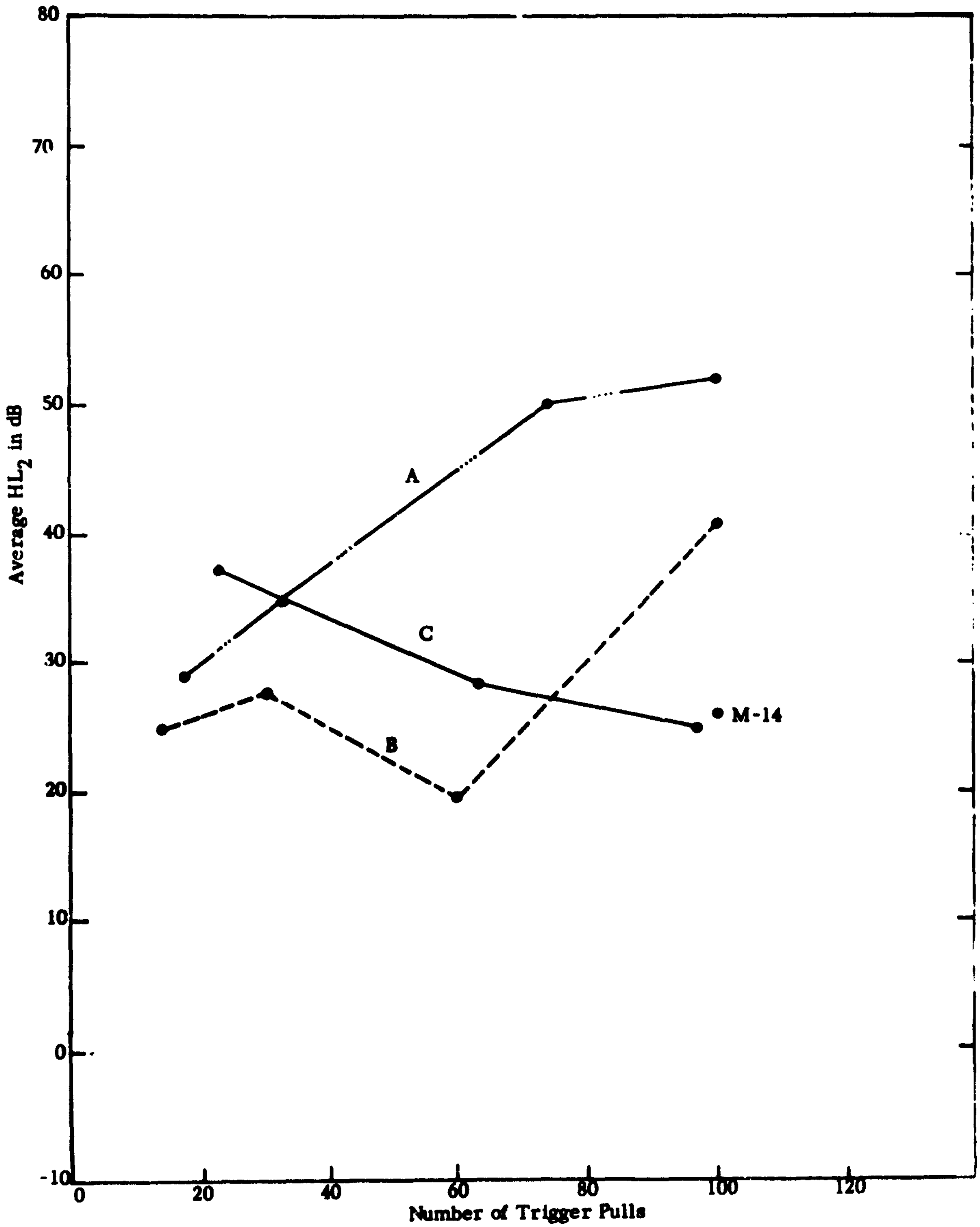


Fig. 3e. AVERAGE HL_2 AS A FUNCTION OF THE NUMBER OF TRIGGER PULLS OF THE TESTED WEAPONS FOR THE 6000-cps AUDIOMETRIC TEST FREQUENCY

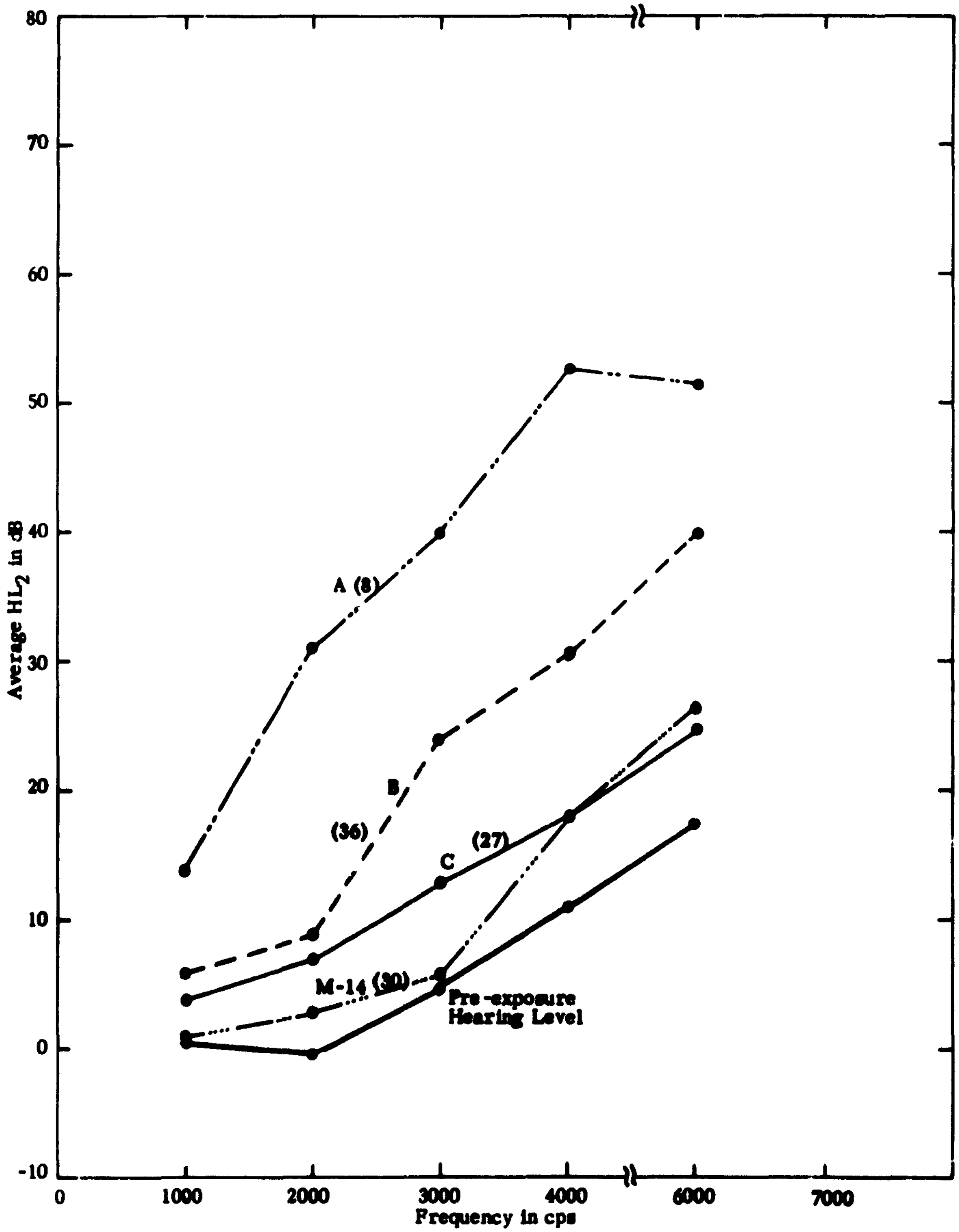


Fig. 4a. AVERAGE HL_2 AS A FUNCTION OF THE AUDIOMETRIC TEST FREQUENCY FOR 100 TRIGGER PULLS OF THE TESTED WEAPONS
(The numbers in parentheses indicate the number of ears averaged.)

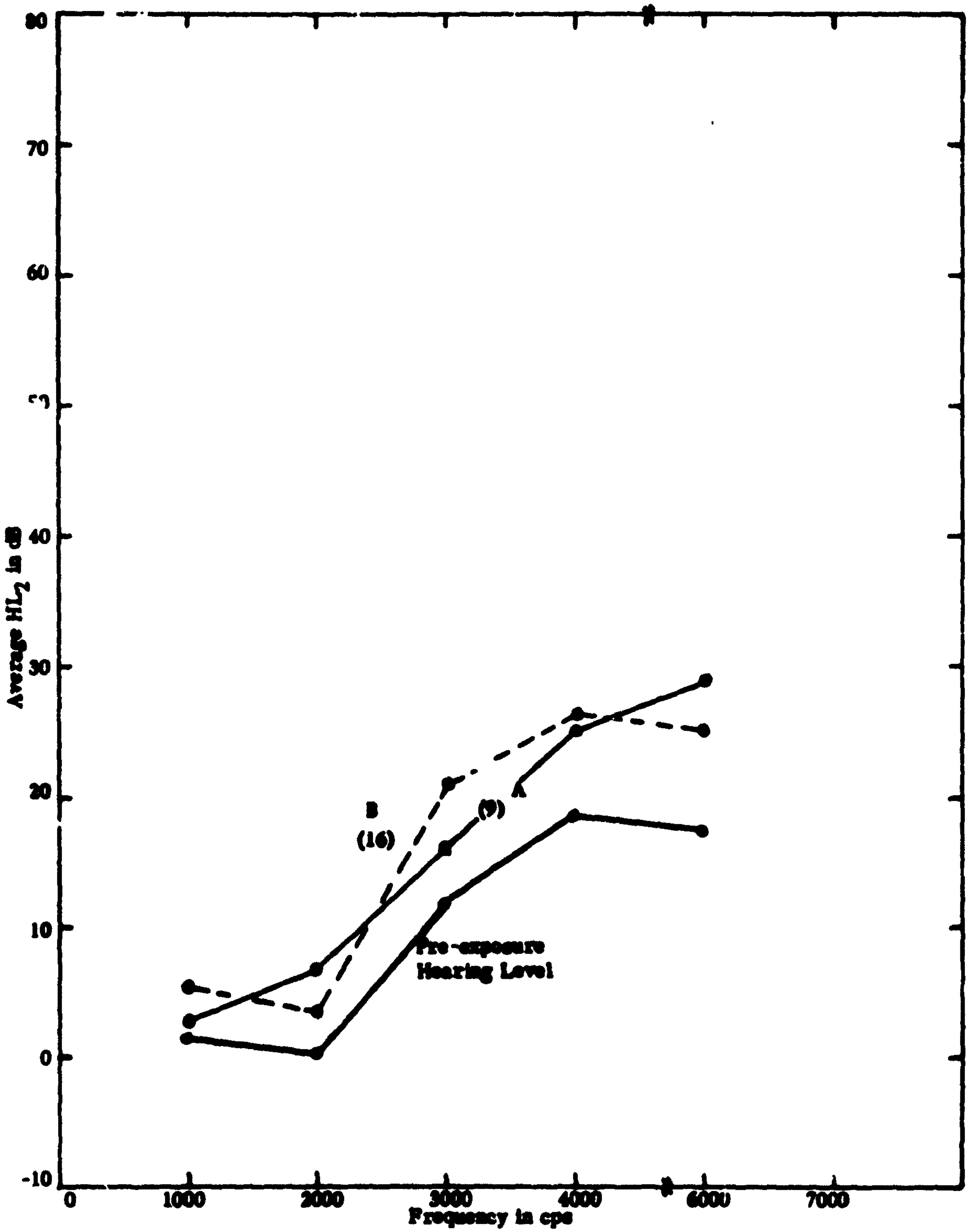


Fig. 4d. AVERAGE HL_2 AS A FUNCTION OF THE AUDIOMETRIC TEST FREQUENCY FOR 15 TRIGGER PULLS OF THE TESTED WEAPONS
(The numbers in parentheses indicate the number of ears averaged.)

Effects of Firing Multiple-Round Bursts

As Table 2 indicates, only one round or projectile was fired per trigger pull, except for certain firings on weapons A and B. Figure 5 shows HL_2 values taken at 4000 cps after firing multiple rounds from these weapons. It is interesting to note that the amount of HL_2 is roughly the same, for a given number of trigger pulls, regardless of whether one, two, or three projectiles were fired.

This finding is perhaps not unreasonable when we consider the short time interval between rounds -- 33 milliseconds for weapon A and 80 milliseconds for weapon B. But in view of the relatively small number of ears involved, it would be desirable to obtain more data before concluding that the damage risk is the same regardless of whether one, two, or three rounds are fired per trigger pull.

There are two possible reasons why HL_2 did not vary with the number of rounds per trigger pull. First, the ear may be "refractory" and incapable of additional fatigue until enough time has elapsed to allow for some recovery from the fatigue the first round engendered. At present, we can only guess what this refractory time might be for these firing conditions. Or, second, the aural reflex (the contraction of a set of middle-ear muscles in response to a loud sound) may have been activated by the first round of fire, thus attenuating transmission of sound from the succeeding round(s), so little or no auditory fatigue was added to that from the first round. This explanation is weakened somewhat by the fact that the time required for the full contraction of the reflex has been reported to be of the order of 100 or 150 milliseconds.

The five-second interval between trigger pulls in the present study was chosen as representative of the interval found during training exercises with weapons that are functioning properly. Since the aural reflex normally relaxes within a second or so following exposure to an impulse sound, it does not protect the ear from the sound of the next round five seconds later.

It might be noted that a very rapid firing schedule -- approximately a round or more per second -- would apparently cause in the average ear the least auditory fatigue or TTS when a given number of rounds are to be fired.

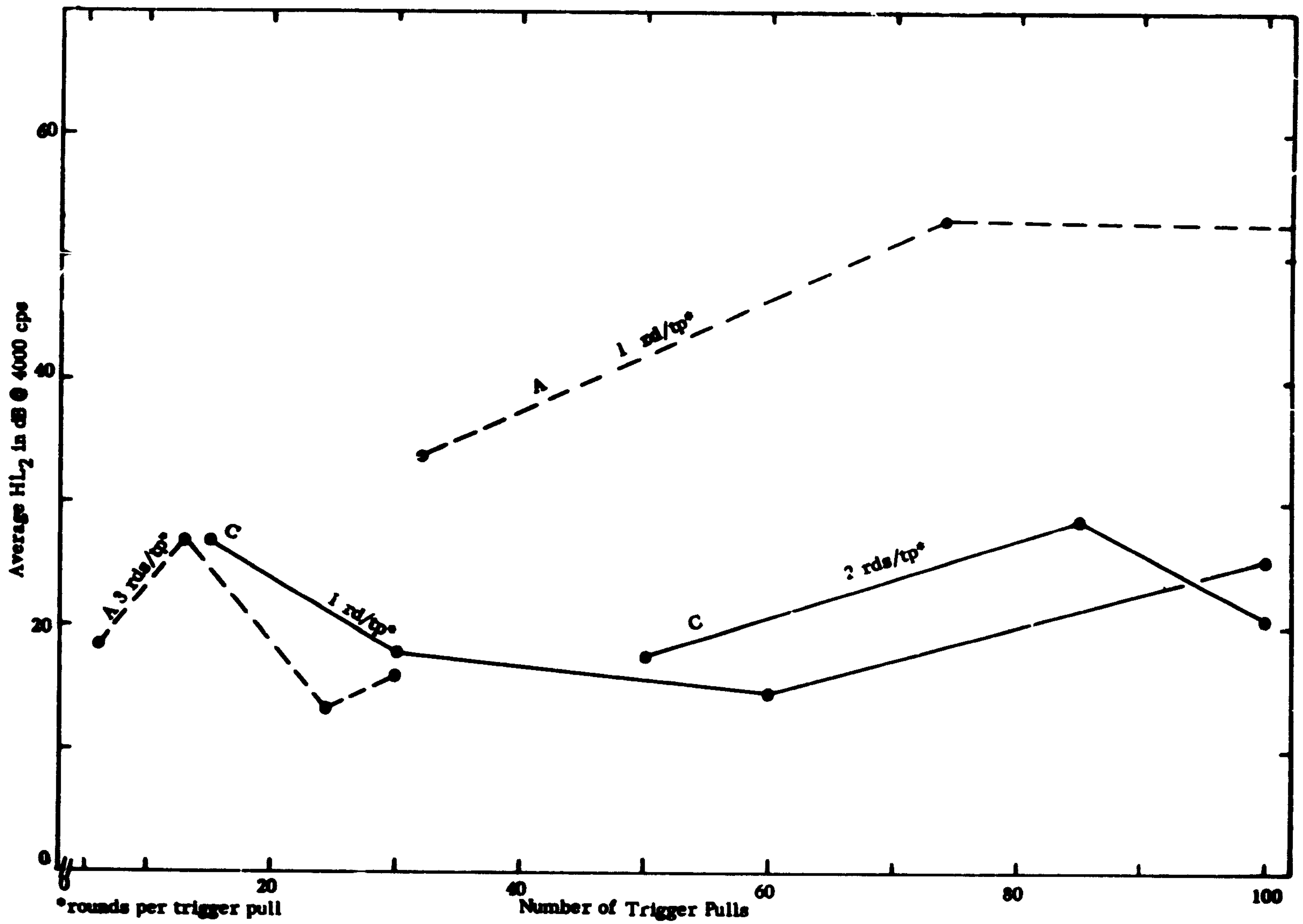


Fig. 5. EFFECT OF FIRING MULTIPLE ROUNDS PER TRIGGER PULL ON HL_2 AT 4000 cps

IMPULSE-SOUND-PRESSURE MEASUREMENTS

A thorough analysis was made of the noise produced by the four weapons used in the auditory experiment. In addition, weapon D and the standard M-16 rifle were measured. This evaluation included determining the peak sound-pressure level (SPL), duration, and time history, and making a spectrum analysis of the pressure wave. These data were obtained at the position of the operator's left ear and at a position 160 inches from the muzzle at an azimuth of 255° from the line of fire. This latter position simulates the location of the adjacent firer's head on a range. Both positions were measured with the operator absent, since his head would have created reflections near the transducer during firing.

The measurements were made using a Ballistics Research Laboratories (BRL) 250KC shock-tube pressure transducer (see Appendix) connected to a Type 531 Tektronix cathode-ray oscilloscope (CRO), which was photographed with a Tektronix CRO camera. The transducer was calibrated at 171 dB in the BRL shock tube on the day of the measurement. The CRO was calibrated at the firing site with a standard cell.

Four oscillograms were taken of the pressure wave each weapon produced:

a. Face-on, at a sweep speed of 50 microsec/cm.

b. Face-on, at a sweep speed of 1 millisec/cm.

c. Grazing, at a sweep speed of 50 microsec/cm.

d. Grazing, at a sweep speed of 1 millisec/cm.

The face-on measurement (Fig. 6a) was taken (a) to see if there was a shock wave at the operator's position, (b) to continuously monitor the transducer's rise-time capability (one microsecond), and (c) to verify the incident pressure at the operator's position. Since pressure was doubled (6 dB) when the transducer was positioned face-on and overshoot was approximately 15 percent, the peak incident pressure could be calculated from this measurement.

Grazing measurements, in which the transducer was rotated 30° from face-on (Fig. 6b), were taken to obtain an accurate time history of the incident-pressure wave. The measured peak incident pressure was then compared to the incident pressure calculated from the face-on measurements. The measurements of each weapon normally varied less than ±0.5 dB in peak pressure.

Fig. 6a. TRANSDUCER POSITION (FACE ON) FOR THE OPERATOR'S LEFT EAR POSITION

Fig. 6b. TRANSDUCER POSITION (GRAZING) FOR THE OPERATOR'S LEFT EAR POSITION

IMPULSE-SOUND-PRESSURE MEASUREMENTS

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Four oscillograms were taken of the pressure wave each weapon produced:

a. Face-on, at a sweep speed of 50 microsec/cm.

b. Face-on, at a sweep speed of 1 millisec/cm.

c. Grazing, at a sweep speed of 50 microsec/cm.

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Fig. 6a. TRANSDUCER POSITION (FACE ON) FOR THE OPERATOR'S LEFT EAR POSITION

Fig. 6b. TRANSDUCER POSITION (GRAZING) FOR THE OPERATOR'S LEFT EAR POSITION

Figure 7 shows the time history and peak sound-pressure level the six weapons produced. Since a 6-dB increase represents a doubling of pressure, weapon A produces eight times the peak pressure of the Standard M-16.

Some evidence indicates that, in addition to the peak pressure, the duration of the pulse is important in determining hearing loss. Figure 7 indicates that all six weapons have approximately the same duration, approximately 200 microseconds, when duration is defined as the time for the pressure wave to increase to its initial positive peak and return momentarily to ambient. When duration is defined as the time required for the envelope of the pressure wave to decrease 20 dB below its peak, the duration is approximately 2 to 2.5 milliseconds.

Measurements taken at 160 inches, 255° from the line of fire indicate that the peak pressure the weapons produced on a range at the adjacent firer's head position would be substantially less (8 - 12 dB) than at the firer's ear.

Spectral analyses were made of the waveforms shown in Figure 7. To do so, appropriate "masks" of the time histories were prepared for a "photoformer" (see Ball, Ref. 1).

The photoformer is a photoelectric device that observes an oscilloscope overlaid with a "mask" of a waveform to be analyzed. The photoformer was made to scan the waveform mask ten times a second and, in so doing, it generated a train of impulses for analysis. The envelope of this impulse train's line spectrum is a close approximation to the true spectrum of the waveform (up to frequencies about 20 times the reciprocal of the impulse duration).

The modulated "line" spectra were measured and analyzed as follows: (a) the output of the photoformer was applied to a Hewlett-Packard Model 302-A Wave Analyzer; (b) a General Radio Type 908-P1 Synchronous Dial Drive changed the center frequency of the constant-bandwidth 302-A analyzing filter at a rate of seven cps per second; (c) the amplitude spectra were recorded with a General Radio Type 1521-A Graphic Level Recorder; and (d) the envelope spectra were then replotted on a log-frequency scale, omitting the 10-cps line structure produced by the 100-millisecond repetition period of the scanning photoformer. These spectra are shown in Figure 8.

If the spectra shown in Figure 8 had been obtained from steady-state stimuli, the greatest hearing loss would be predicted one octave above the stimulating frequency component with the highest sensation level (usually this would be the frequency component with the highest sound-pressure level). Since the spectra of the impulses from these weapons appear to be peaked broadly at 2000 cps, the maximum auditory fatigue should occur at 4000 cps. Our audiometric data (Figs. 4a-4d) would, in general, agree with this prediction.

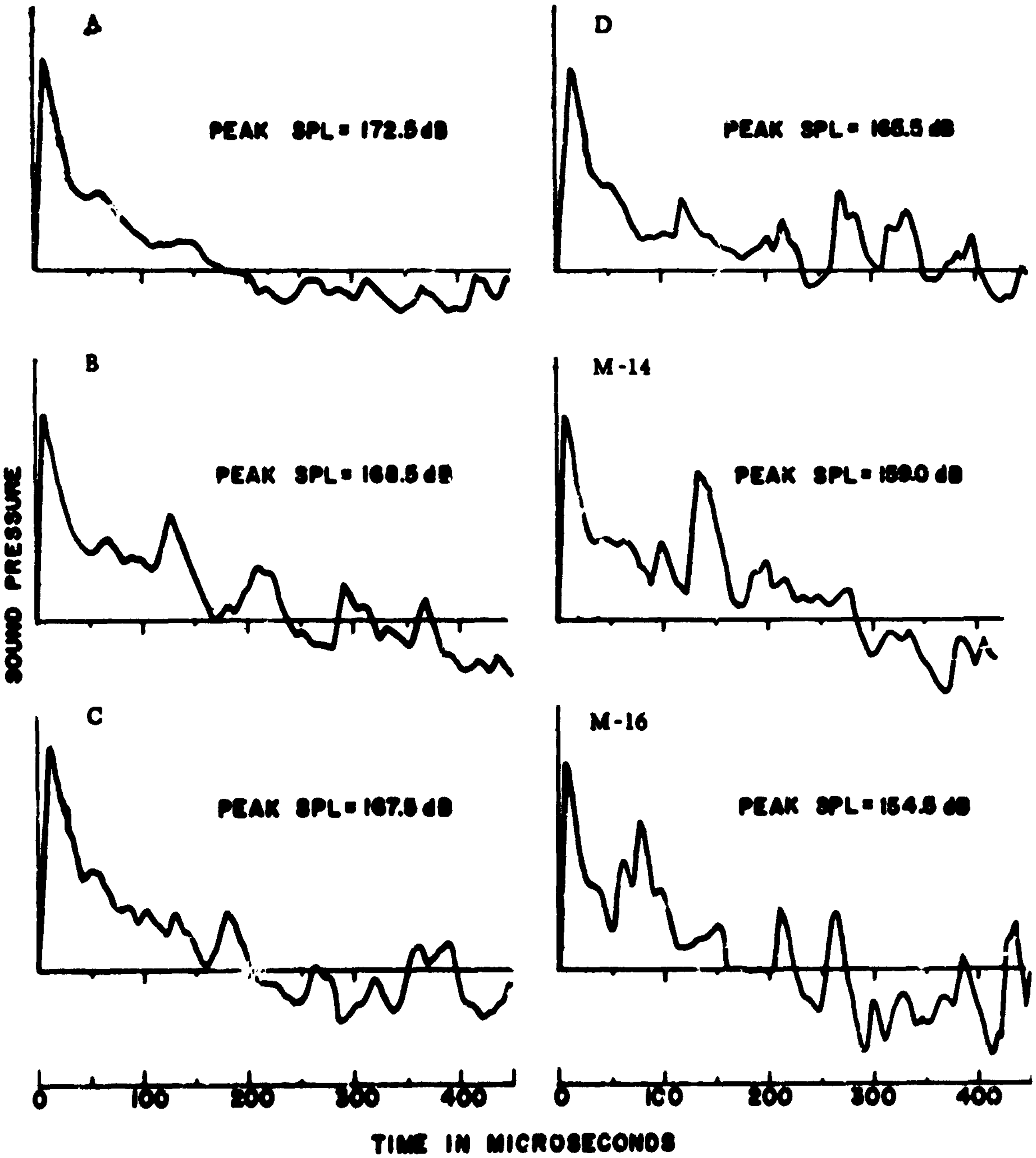

Fig. 7. TIME HISTORY AND PEAK SOUND-PRESSURE LEVEL FOR THE SIX MEASURED WEAPONS
(The peak levels of the waveforms have been adjusted to equal amplitudes.)

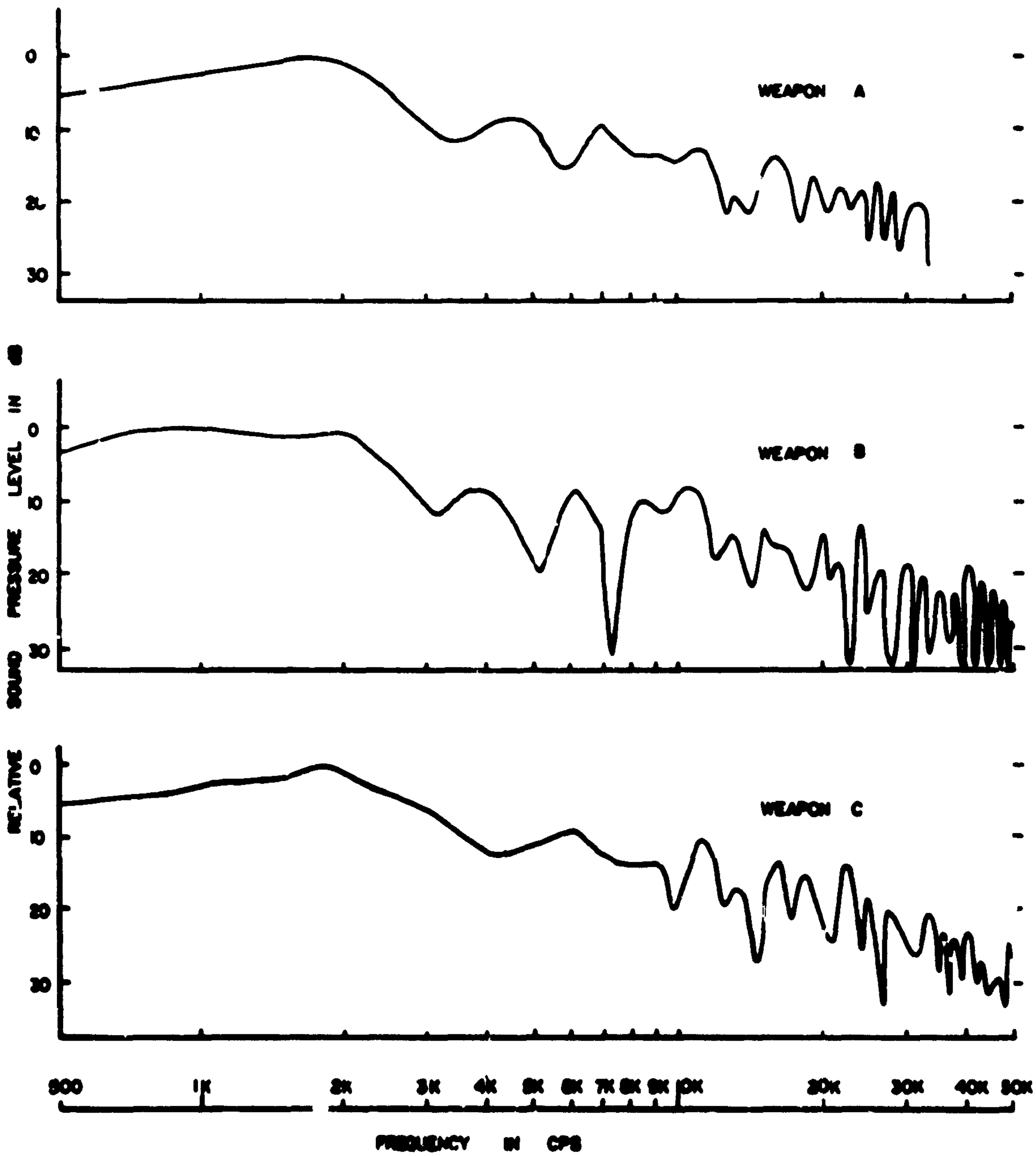

Fig. 8a. SPECTRAL ANALYSIS OF WEAPONS A, B, AND C

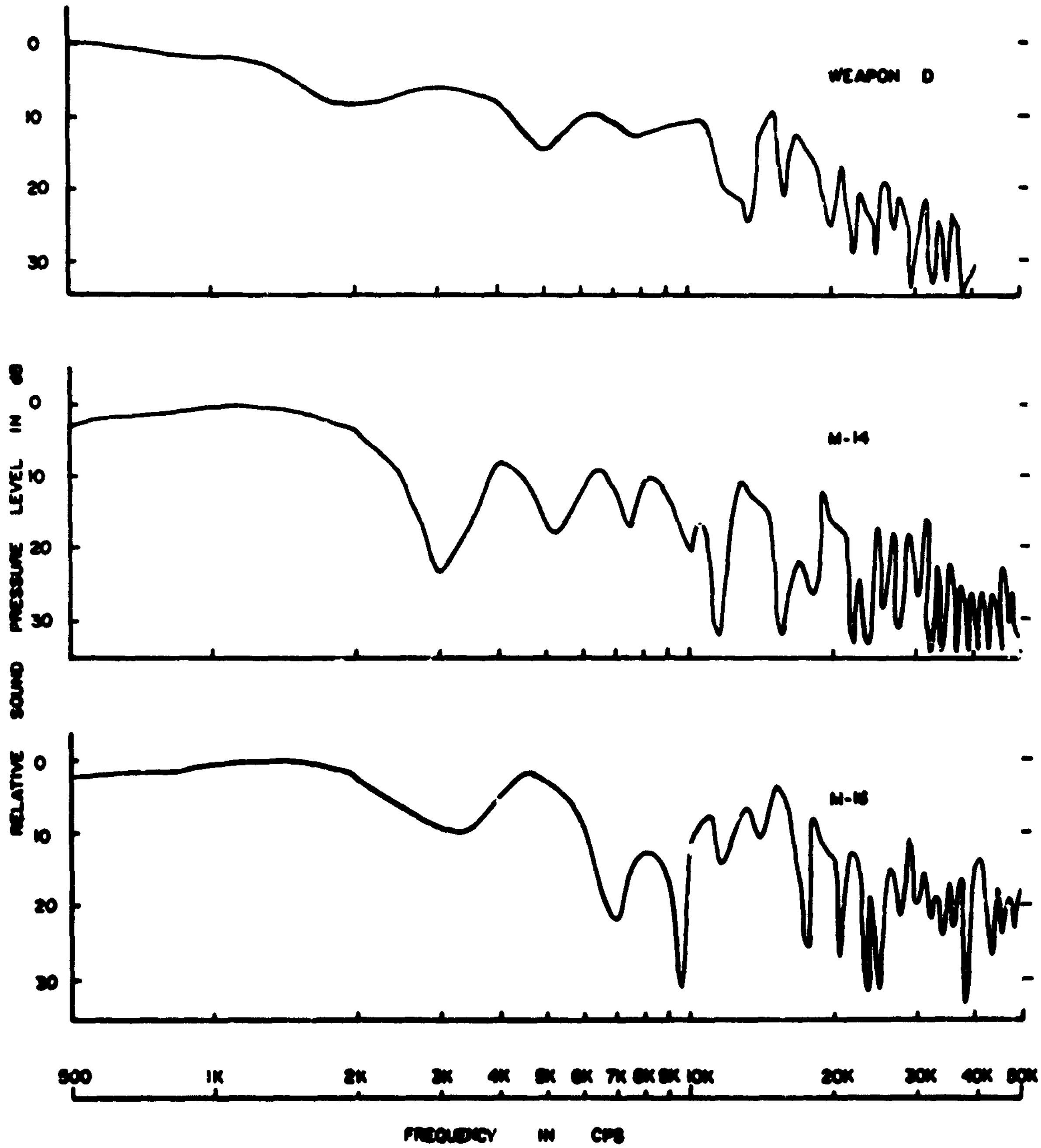

Fig. 8b. SPECTRAL ANALYSIS OF WEAPON D, THE M-14, AND THE M-16

However, these spectra were obtained by analyzing the acoustical waveform of impulses at the entrance to the ear canal. Since characteristics of the middle ear's mechanical transmission system may interact with the temporal aspects of one impulse's waveform somewhat differently than with those of another, the impulses' acoustic spectra may be changed differentially by transmission through the middle ear. We need further knowledge about the middle-ear structures' transfer characteristics for brief sound impulses before we can be certain that there is a real correlation between impulse spectra and frequency where there will be auditory fatigue.

CORRELATION BETWEEN PEAK SOUND-PRESSURE LEVEL OF GUN NOISE AND HEARING LOSS

Table 6 ranks the weapons by peak sound-pressure levels at the firer's head position and by HL_2 after firing. For these particular weapons, there is apparently a perfect correlation between peak sound-pressure levels and damage risk to hearing; in other words, the average HL_2 decreases from weapon to weapon as the peak sound-pressure levels decrease.

There is some evidence, however, that in addition to peak sound-pressure levels, other aspects of the pressure wave (e.g., rise time, duration, spectrum, etc.) also influence the effect gun noise has on hearing. The time histories of the weapons were similar in most respects except peak sound-pressure level. But it does not necessarily follow that, for weapons having different rise and decay time characteristics, the peak impulse levels will show the same strong correlation with HL_2 produced by the impulses used in this study.

TABLE 6

Q_3 (75th Percentile) for HL_2

Weapon	Peak SPL (dB re 0.0002 dynes/cm^2)	No. Trigger Pulls	Test Frequencies in cps									
			500[a]	1000	2000	Avg.	1000	2000	3000	Avg.	4000	6000
A	172.5	102	11[a]	26	56	31	26	56	84	55	84	91
		74	7	22	50	26	22	50	78	50	85	86
		32	0	10	16	9	10	16	27	18	60	57
				Grand Average		22				41		
B	168.5	100	0	10	12	7	10	12	43	22	52	57
		60	0	8	10	6	8	10	22	13	25	29
		30	0	6	9	5	6	9	24	13	24	55
				Grand Average		6				16		
C	167.5	97	0	7	10	6	7	10	12	10	14	27
		63	0	11	12	7	11	12	38	20	55	56
		23	0	12	18	10[b]	12	18	51	27[b]	65	73
				Grand Average		6				15		
M-14	159.0	100	0	7	8	5	7	8	14	10	33	45

[a] HL_2 for 500 cps is estimated.

[b] Only five ears involved in this firing condition, and results are not included in Grand Average.

HL_2 AS A FUNCTION OF PEAK SOUND-PRESSURE LEVEL

It would be most helpful if we could specify impulse-noise limits for weapons so users would not suffer significant amounts of hearing loss. Unfortunately, our data are probably insufficient to define tolerable impulse-noise limits adequately, even if certain rather far-reaching assumptions are made. Yet they are, to our knowledge, the best available data that bear directly on this problem.

Figure 9 shows HL_2 data as a function of the peak SPL, for some of the weapons fired. We have taken the liberty of extrapolating HL_2 trends at the different audiometric test frequencies to sound-pressure levels below 159 dB. These curves, in Figure 9, suggest that there are indeed certain critical peak-pressure levels, above which the ear seems to be "traumatically" affected so that threshold shifts increase at a tremendous rate for each one-dB increase in level. For these weapons, that critical SPL appears to be about 168 dB for 25 percent of the ears.

It is perhaps worth noting that, below this apparently critical level, HL_2 increases with peak SPL much as with steady-state noise, where a one-dB increase in SPL causes about a two-dB increase in TTS when TTS falls between about 15 to 50 dB.

COMPARISON OF HEARING-LOSS DATA WITH "DAMAGE-RISK CRITERIA"

As yet, there is no certain way to predict how many exposures to a given impulse-noise condition will produce a permanent hearing loss similar to the temporary loss suffered from a single exposure. However, the following considerations do permit a guess, with some reservations, that the HL_2 levels found in the present studies could eventually become permanent:

a. With steady-state noise, it has been found that the amount of permanent hearing loss after several years of work-day exposure to a given noise environment is about equal to the TTS_2 that one day's exposure causes in the average normal ear. This relation appears to hold at least when the TTS_2 values average about 10-30 dB.

b. It is, no doubt, unrealistic to expect a soldier to fire as often as in these tests (up to 100 trigger pulls) nearly every day for a number of years. On the other hand, he will be exposed to other severe noise conditions to some unknown degree -- when riding in a tank, firing other weapons, etc.

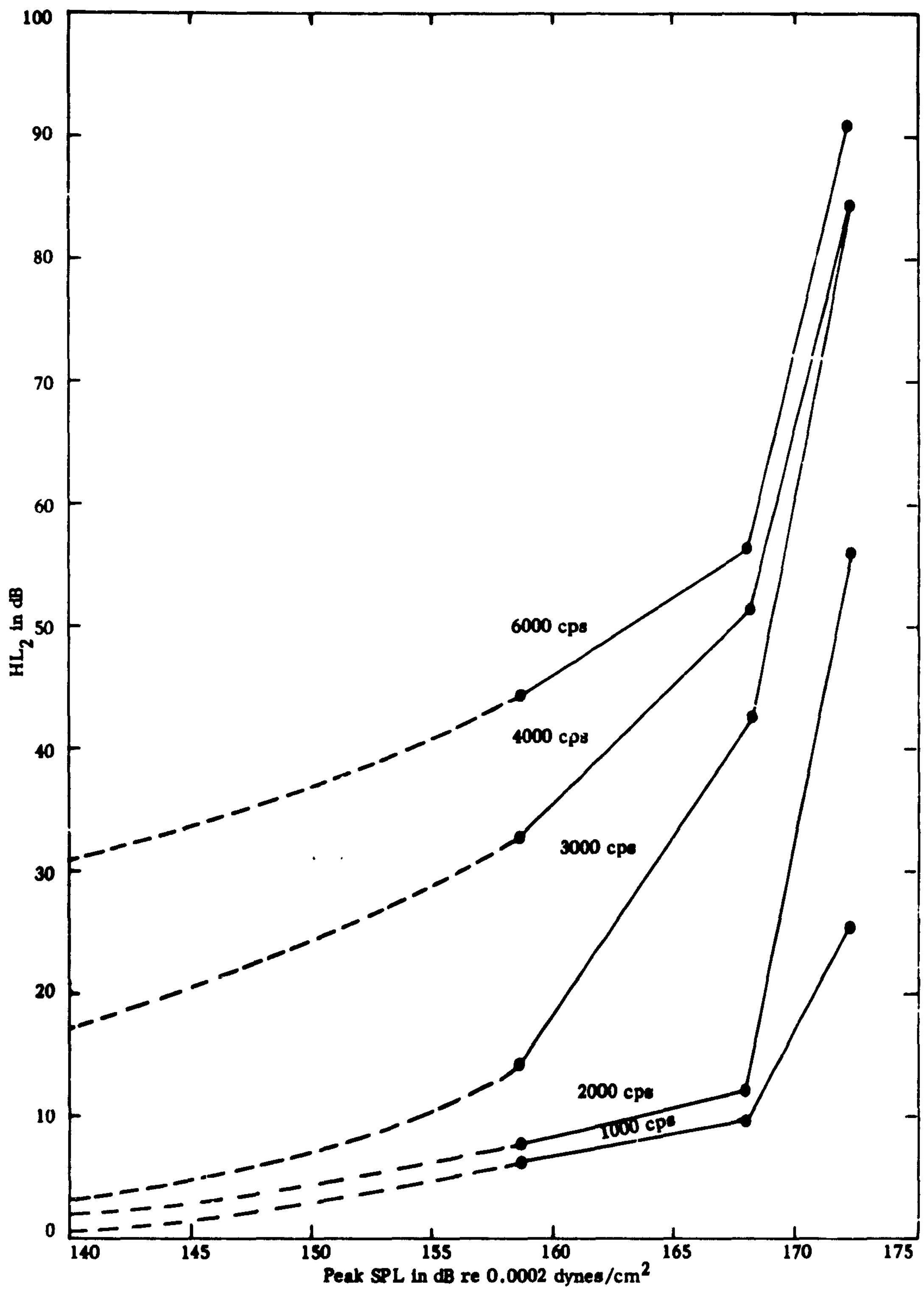

Fig. 9. HL_2, FOR Q_3, AS A FUNCTION OF PEAK SPL FOR THE A, B, AND M-14 WEAPONS FIRING 100 TRIGGER PULLS
(By audiometric test frequency.)

If we tentatively accept, at least for present purposes, the proposition that TTS_2 may eventually become a permanent threshold shift, or hearing loss, the HL_2 values in Table 6 represent the approximate amount of permanent hearing loss that would be equaled or exceeded in 25 percent of the soldiers habitually firing a given weapon for various numbers of trigger pulls per day.

In addition to the Q_3 values for the individual test frequencies, the average of the Q_3 values for 500, 1000, and 2000 cps, and the average Q_3 values for 1000, 2000, and 3000 cps are given in Table 6. These averages are presented because they are being used (6) or have been suggested for use (4) in evaluating the ability to understand speech. An average of 15 dB loss at these three frequencies has been proposed as the degree of hearing loss at which compensation for handicap in hearing speech should begin.

It must be emphasized that assuming the TTS_2 after impulse noise will eventually become a permanent threshold shift with repeated exposures is, at the very best, no more than an educated guess. It is quite possible that the development of permanent hearing loss from impulse noise follows a much different pattern than after exposure to so-called steady-state noise. In that regard, we are particularly impressed, and dismayed, by the great variability of the threshold shifts different ears exhibit after exposure to gun noise. Indeed, it appears that the distribution of sensitivity to hearing loss from exposure to impulse noise may be bimodal -- that there are "tender" ears and "tough" ears. This bimodality is suggested in the sample distributions of HL_2 for weapon B, as shown in Figure 10.

This bimodality, if indeed real, might reflect invariant differences between "tough" and "tender" ears, or the same ear might suddenly change in susceptibility -- that is, be highly resistant to damage up to a "break point," beyond which it tends to become suddenly and severely affected or traumatized.

Further caution is indicated in accepting our assumption that TTS predicts eventual permanent hearing loss if one believes that the ears used in our tests represent a select group of "toughened" ears. It is possible that the more tender-eared soldiers had previously been removed or eliminated from our sample by normal selection and medical procedures during initial classification, training, and general service. If this is the case, our data underestimate the damage risk to hearing for the gun noises tested.

However, the data and the considerations above suggest these tentative conclusions:

a. Firing the M14 rifle 100 times a day will eventually cause significant (more than 15 dB) hearing losses at 4000 and 6000 cps in more than 25 percent of the people exposed; but it will not cause significant losses at 3000 cps or at lower frequencies, except in the most tender-eared persons.

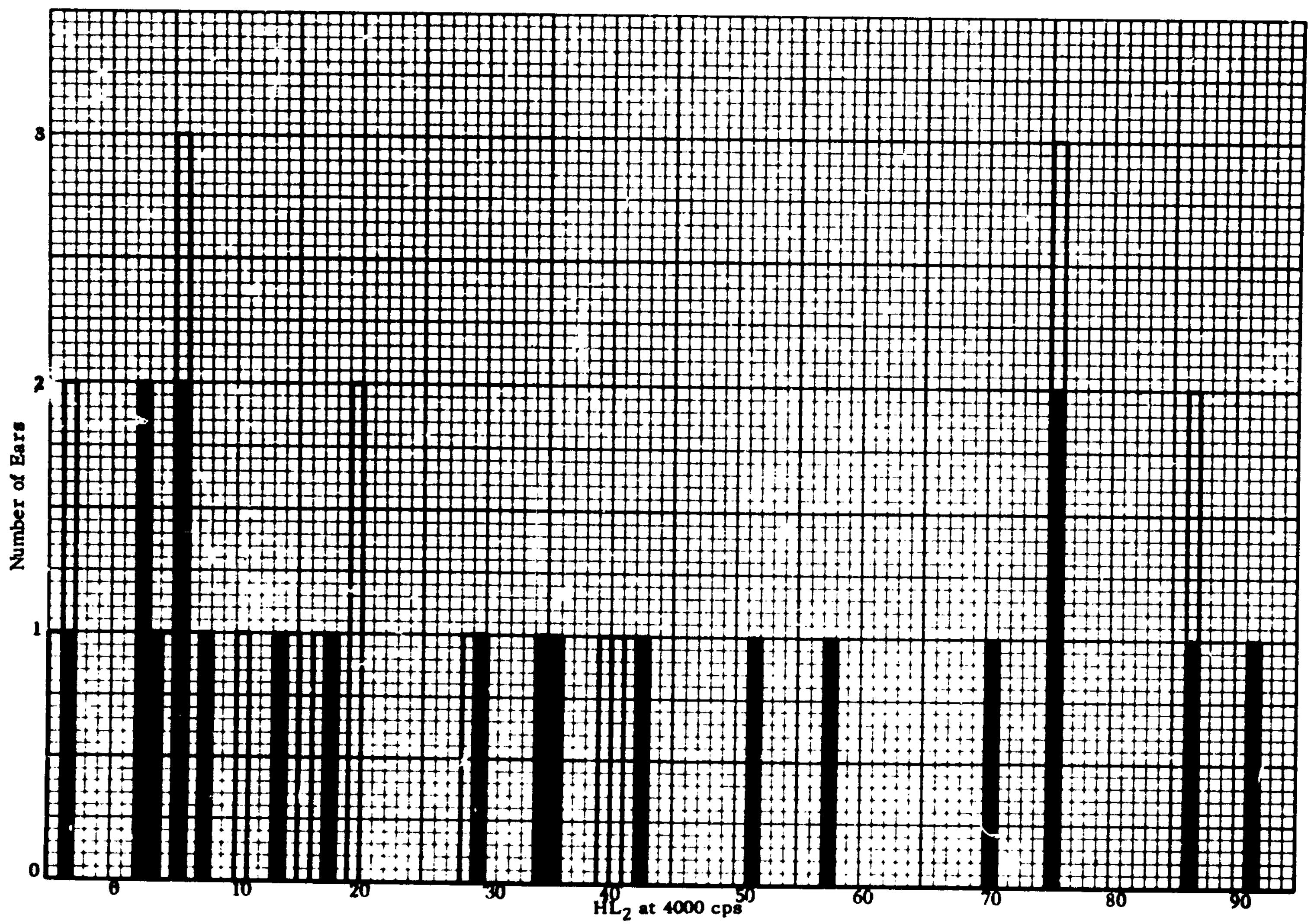

Fig. 10. HL_2 AT 4000 cps FOR THE NEAR EAR (SHADED AREA) AND THE FAR EAR (OPEN AREA) AFTER FIRING 100 SINGLE-ROUND TRIGGER PULLS USING WEAPON B

b. Weapons B and C appear on the average to have about equal potential for causing permanent hearing loss. More than 25 percent of people who habitually fire 30 or more rounds a day with these weapons would be expected to develop permanent hearing losses that would be compensable by the criterion of average HL at 1000, 2000, and 3000 cps. Somewhat less than 25 percent -- perhaps ten percent or thereabouts -- would have compensable hearing losses under the criterion of average HL at 500, 1000, and 2000 cps (the VA bases its compensation schedule on HL at these frequencies).

c. Weapon A would presumably cause compensable permanent hearing losses in more than 25 percent of people who habitually fire it more than 30 times a day, even by the criterion of average HL at 500, 1000, and 2000 cps. Weapon A would probably produce much more compensable loss than weapons B or C.

Predicted Hearing Loss from Gun Noise

We have estimated from Figure 9, on the basis of the distributions of HL_2 we found in this study, the eventual permanent hearing level (ASA Standard) expected in certain percentages of ears after repeated exposure to shoulder-rifle noise of various peak SPLs at the listener's ears. The results are shown in Table 7. This table should be used with caution, since some unproved assumptions were used in deriving it.

TABLE 7

Predicted Permanent Hearing Level (ASA Standard) Equaled or Exceeded in 50%, 25%, and 10% of Ears After Repeated Daily Exposure[a]

	Test Frequency in cps														
	1000			2000			3000			4000			6000		
Peak SPL	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%
170 dB	0	15	25	10	25	35	35	55	70	45	65	85	50	70	90
165 dB	0	9	16	0	10	20	12	32	42	25	45	60	47	52	67
160 dB	0	7	15	0	8	16	0	18	25	15	35	45	25	45	60
150 dB	0	3	10	0	4	15	0	8	15	10	25	35	20	40	50
140 dB	0	0	0	0	2	5	0	2	10	3	18	30	10	30	45

[a]To about 100 rounds, at five-second intervals, of the noise from shoulder-rifles. Peak SPL measured at listener's ears.

USE OF EAR-PROTECTIVE DEVICES

All of the audiometric data reported above were obtained from ears that were unprotected from the gun noise used in these tests. Typical properly fitted earplugs or earmuffs can provide 20-40 dB sound attenuation in the important frequency region from 500 to 4000 cps. Hence using these protective devices would certainly provide ample protection against the noise of even weapon A, except possibly for the frequency region above 4000 cps. The effective level of that weapon's noise would be reduced to an eff tive peak sound-pressure level of 140 dB or so.

The proper use of ear protectors, even though presumably confined largely to training and only certain operational or combat conditions, should help prevent hearing losses. Thus their use would not only preclude the individual hardship of a hearing handicap, but it would also preserve the hearing of military personnel so they could perform their jobs more effectively under operational conditions.

But even disregarding objections about comfort, cleanliness, cost, etc., ear protectors often meet resistance on the ground that they reduce the soldier's operational effectiveness. In particular, it is believed that earplugs or earmuffs prevent the man from hearing spoken commands or weak auditory signals important to his well-being and his job performance.

This part of the report will examine how earplugs or earmuffs affect the user's ability to understand speech, both for users with normal hearing and for those with hearing loss.

Speech Reception when Wearing Earplugs or Earmuffs

Hearing and understanding speech or other auditory signals depends upon several interacting factors:

a. The person's threshold of hearing.

b. The intensity level and spectrum of the speech or other auditory signal.

c. The intensity level and spectrum of any masking noise present.

d. Whether a person is listening open-eared or with his ears plugged or covered.

e. The amount of sound attenuation the earplugs and/or earmuffs provide at different frequencies.

In Figures 11a, 11b, and 11c, we have attempted to show graphically how these various factors interact with each other.

Without earplugs, even the person with good hearing will not hear some of the weaker parts of speech uttered at a conversational level in a quiet environment by a talker approximately three feet away. When wearing earplugs that afford about 18 dB attenuation at 200 cps, 23 dB at 1000 cps, and 30 dB at 4000 cps, the person with hearing loss is unable to hear any of the speech; the person with good hearing can perceive only part of the speech, but probably enough to understand it.

Figure 11b shows how much of a fairly intense speech signal would be audible when the same persons, with and without earplugs, were in an ambient noise field such as in an idling personnel carrier.

We see in Figure 11b that, in moderate noise, the person with hearing loss who is not wearing earplugs hears as much of the speech signal as the person with good hearing does.

Figure 11b also shows that the person with good hearing is able to perceive as much of the speech when he is wearing earplugs as when he is not -- the earplugs attenuate both the speech signal and the noise equally -- whereas the man with hearing loss is unable, when wearing earplugs, to hear some of the speech components he could hear without them. His hearing level, or threshold, exceeds the noise's masking level at some frequencies when the earplugs reduce the noise level. In these frequency regions, it is the hard-of-hearing person's threshold of hearing -- not the background noise -- that somewhat limits his reception of parts of the speech signal.

If we increase the noise by about 30 dB, as inside a moving personnel carrier, we see (Fig. 11c) that the hard-of-hearing ear and the -10 dB ear perceive all the components of the speech signal they are capable of hearing, whether or not they are wearing earplugs; this is because the masking noise spectrum determines which of the speech components will be heard, even after attenuation of the noise and the speech by the earplugs. As a matter of fact, both persons would understand the speech more easily when wearing earplugs than when they were not (3).

The following conclusions, then, seem indicated:

a. Earplugs or earmuffs <u>should not</u> be worn when:

(1) The listener is in the quiet, particularly if he has a hearing loss.

(2) The listener is in noise, if the noises' spectrum level between about 200 and 4000 cps is less than the sum of the person's HL at those frequencies and the attenuation that the earplugs or earmuffs afford in this frequency range.

b. Earplugs and/or earmuffs should be worn when:

(1) The noise spectrum exceeds the sum of HL and the attenuation earplug and/or earmuff afford. Wearing earplugs or earmuffs under these conditions will not only prevent hearing loss from the noise, but it will also tend to improve understanding for speech and other auditory signals.

c. The conclusion seems inescapable that, in terms of hearing and understanding speech or other weak auditory signals, hard-of-hearing soldiers should not wear ear protectors unless they are in very intense noise environments. Unfortunately, without ear protectors, some of these people may incur further hearing losses with continued exposure to sufficiently intense noise, at least up to a point.

d. It appears equally clear that, if soldiers with good hearing do not wear suitable and effective ear protectors, a significant proportion will develop partial noise-induced deafness.

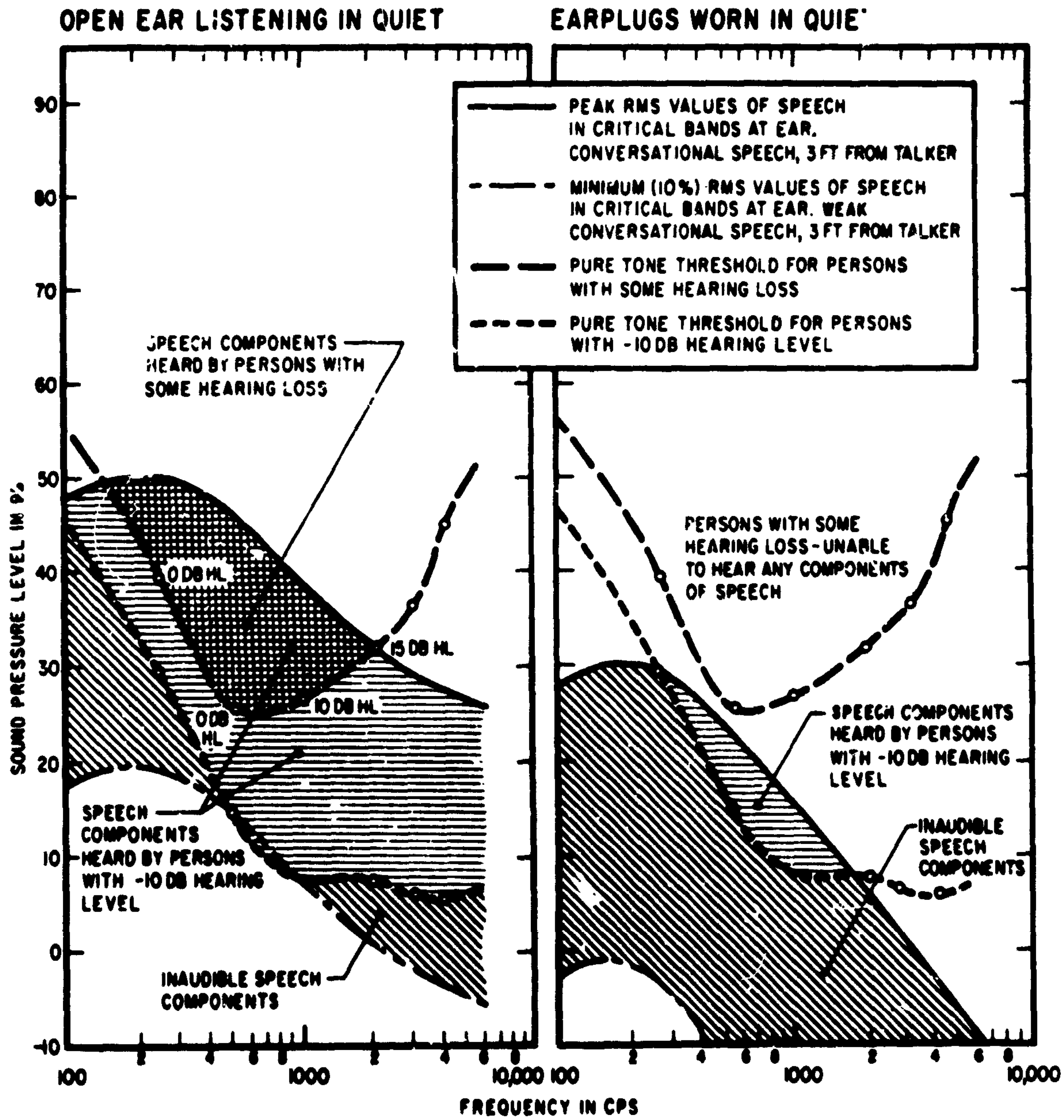

Fig. 11a. THE EFFECT OF WEARING EARPLUGS IN A QUIET ENVIRONMENT FOR PERSONS WITH NORMAL HEARING AND PERSONS WITH SOME HEARING LOSS

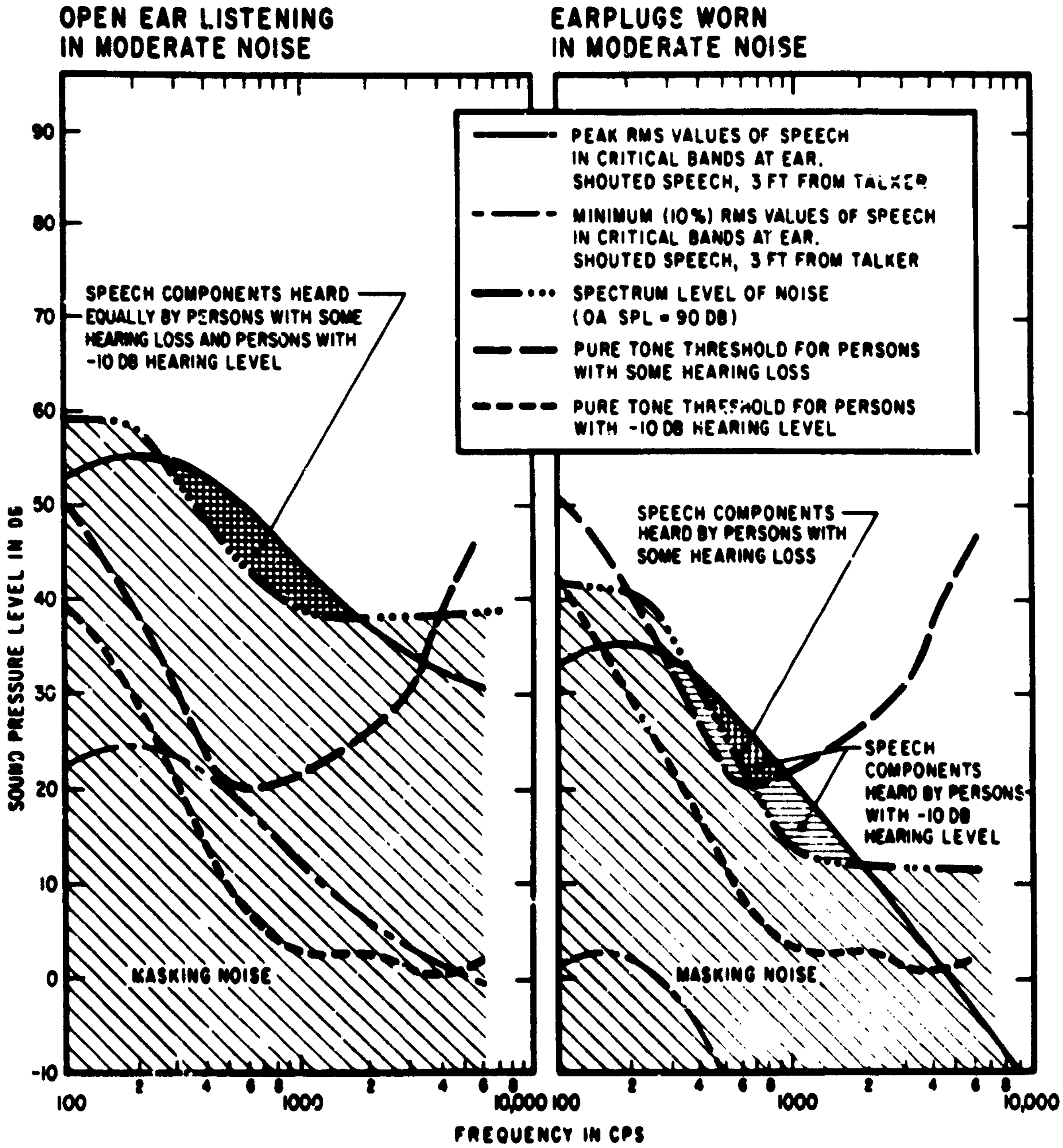

Fig. 11b. THE EFFECT OF WEARING EARPLUGS IN MODERATE NOISE FOR PERSONS WITH NORMAL HEARING AND PERSONS WITH SOME HEARING LOSS

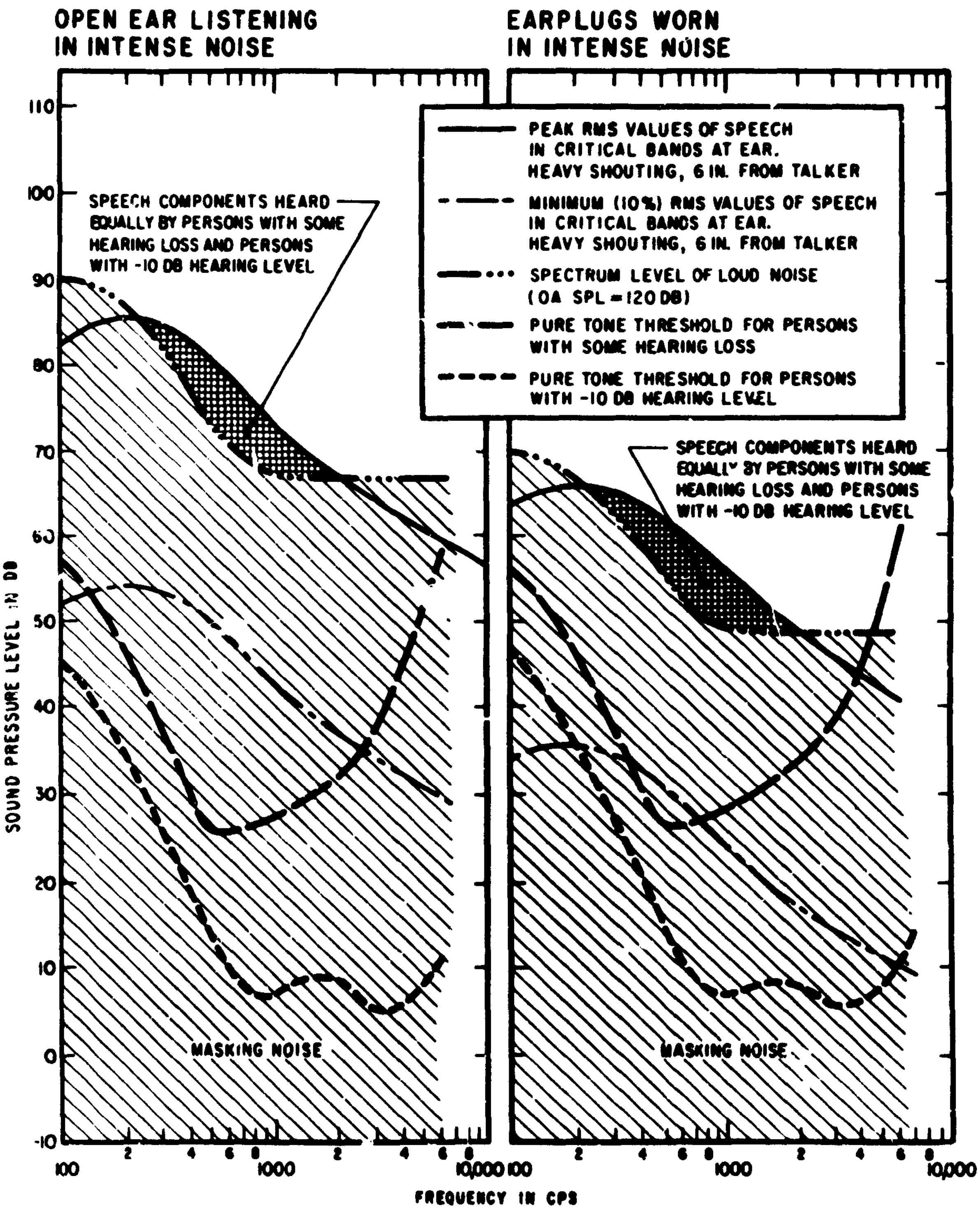

Fig. 11c. THE EFFECT OF WEARING EARPLUGS IN INTENSE NOISE FOR PERSONS WITH NORMAL HEARING AND PERSONS WITH SOME HEARING LOSS

SUMMARY

Tests of the auditory acuity of both ears of 178 soldiers before and after they fired several shoulder rifles at the rate of one trigger pull every five seconds, and an analysis of the effects of wearing ear-protective devices on the reception of speech signals in noise, indicate the following:

a. Repeatedly firing as many as 100 trigger pulls per day with the M-14 rifle would probably cause, in about 25 percent of the firers, significant permanent hearing loss at frequencies of 4000 cps and up, but not at frequencies of 3000 cps and below.

b. Repeatedly firing 60 to 100 trigger pulls per day with weapons B or C would probably cause, in about ten percent of the firers, significant permanent hearing loss in the frequency region from 1000 to 2000 cps and up.

c. Repeatedly firing 30 to 100 trigger pulls per day with weapon A would probably cause, in 25 percent or more of the firers, significant permanent hearing loss in the frequency region from 500 to 2000 cps and up.

d. The peak sound-pressure levels measured at the firers' ear position for various weapons were as follows:

M-16	154.5 dB
M-14	159.0 dB
Weapon D	165.5 dB
Weapon C	167.5 dB
Weapon B	168.5 dB
Weapon A	172.5 dB

e. Hearing losses greater than 15 dB would appear to occur in something over ten percent of the people exposed to impulse noise similar in time-pattern characteristics to those used in this study:

(1) At and above 4000 cps when the peak SPL exceeds 140 dB.

(2) At and above 3000 cps when the peak SPL exceeds 150 dB.

(3) At and above 2000 cps when the peak SPL exceeds 160 dB.

(4) At and above 1000 cps when the peak SPL exceeds 165 dB.

Therefore, a criterion of acceptability for impulse noise in terms of peak SPL might be as follows:

(1) In terms of VA compensation standards -- 160 dB.

(2) In terms of proposed standards for hearing impairment for speech (use of frequencies up to 3000 cps) -- 150 dB.

(3) In terms of good hearing for speech as well as other sounds (sonar, for example) -- 140 dB.

f. Earplugs or earmuffs would protect hearing adequately during exposure to gun noise -- but, particularly for people with hearing loss, would reduce the ability to perceive speech or other weak auditory signals, except in the presence of rather intense masking noise.

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APPENDIX

BALLISTICS RESEARCH LABORATORIES SHOCK TUBE GAGE

Manufacturer:	Ballistics Research Laboratories
Model:	"Yellow Dot"
Principle:	Piezoelectric
Type:	Incident Air Blast
Range:	0.1 to 500 psi
Dimensions:	Length 0.625" Diameter 0.5" Sensitive Surface Diameter 0.21"
Construction:	303 Stainless with nylon pressure plate
Mounting:	Flush mounted, case threaded 1/2-20 NF
Description:	Sandwich type G. E. 488A lead zirconate ceramic disc mounted to the surface of a short lead cylinder
Recording System:	BRL electrometer cathode follower and Tektronix 541 oscilloscope with 53-54 D preamplifier
Test Data:	Output: 20pC/psi and 100 mv/psi open circuit Capacitance: 120 pF Resistance: over 10,000 megohms Non-linearity: less than 1-1/2% F. S. Hysteresis: Negligible Repeatability: Within 1% Resolution: Continuous Ringing Frequency: 250 KC, not excited below mach 5 Rise Time: 1 microsecond Ringing Time: 60 microseconds to 10% F. S. Useful Temperature Range: 0 to 50° C. Acceleration Sensitivity: Not well determined at present
Remarks:	Transducer is sensitive to changes in ambient temperature. Output at 50° C. is 125% that at room temperature.